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WIRE STEM OF CABBAGE

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WIRE STEM OF CABBAGE[1]

LEVI OTTO GRATZ

The cabbage crop ranked sixth in 1919 and 1920, and seventh in 1921, in the number of commercial acres produced among fifteen leading truck crops grown in the United States. During that time New York produced 23,287 acres of late cabbage per annum, with an average yield of 8.2 tons per acre.[2] In this State the crop is second only to potatoes, and is the most important of all the other vegetables grown.[3] Its total value, based on average prices from 1920 to 1923, inclusive,[4] approximates three million dollars yearly. From 1919 to 1921, inclusive, New York ranked ninth in yield per acre among twenty-one leading States for which figures are available.[2]

It is an established fact that the early market bids the highest prices. This is especially true for the early crop. On the Buffalo wholesale curb market, in the vicinity of which these investigations were first undertaken, it is not uncommon for the growers to sell their first cabbage about the middle or latter part of July for eight cents or more per head, and several weeks later to sell cabbage of higher quality for less than half this price. Later in the season an overstocked market occasionally forces the grower to return from market with part of his load unsold. It is therefore apparent that a short delay in the maturing of the early crop may mean a large loss to the grower. There are numerous factors which may cause such a delay, as, for example, adverse environmental conditions or disease of the seedlings.

THE DISEASE

NAMES, HISTORY, AND GEOGRAPHICAL RANGE

The general term *damping-off* may be applied to the early stage of this particular disease. By this term is meant the killing of the tissues of the seedling at the surface of the ground so that eventually the plant topples over. More specific names, as *black rot* (Duggar and Stewart, 1901),[5] *black shank disease*,[6] and *stem rot* (Fawcett, 1909), have been applied to

[1] Also presented to the Faculty of the Graduate School of Cornell University, June, 1923, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

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[2] U. S. Dept. Agr., Yearbook **1921**:647–649. 1922.

[3] Fourteenth census of the United States, taken in the year 1920, vol. 5, p. 820–831. 1922.

[4] U. S. Dept. Agr., Weather, Crops, and Markets **4**:680. 1923.

[5] Dates in parenthesis refer to bibliography, page 59.

[6] U. S. Dept. Agr., Bur. Plant Ind., Plant disease bul. 1, p. 49. 1917.

the disease in the past. The last-named term is most frequently used in western New York. These names are used rather than the term *damping-off*, since diseased seedlings often do not topple over and may apparently recover. In fact, plants with slight lesions, though undoubtedly permanently injured, are frequently planted in the field. None of these terms appear to the writer to be sufficiently descriptive. *Damping-off* is too general and applies to the early stage only. *Black rot* is already in general use for the bacterial disease caused by *Pseudemonas campestre* (Pammel) E. F. Smith. *Black shank disease* only partially conveys the idea intended. *Stem rot* is inaccurate, as the stem may not exhibit a pronounced rot, especially in the later stage of the disease. In view of these facts the writer suggests the name *wire stem*. This is more desirable since most of the plants are not killed outright by the primary attack, but emerge with a characteristically tough, wiry stem (Plate I). This name accurately conveys the idea suggested by the symptoms.

The first definite reference to this disease was by Atkinson (1895). He describes in detail the damping-off of seedlings of such plants as radishes and lettuce, and states that "egg plants and cabbages as well as others are known to be affected." He attributes this to a "sterile fungus" now known as *Corticium vagum* B. & C. Duggar and Stewart (1901) report the disease on cabbage seedlings from Cairo, Illinois, in 1898, and also on cauliflower seedlings at Geneva, New York. They consider *Corticium vagum* the causal organism. Fawcett (1909) observed the damping-off of cabbage seedlings in Florida, caused by this fungus. Six years later Sherbakoff (1916) reported isolating the fungus from cabbage, cauliflower, and other hosts in Florida, and during the following two years he presented data concerning some phase of experimental work on damping-off (1917, a and b). During the past few years the disease has been reported from Washington, Utah, Missouri, Indiana, Ohio, Alabama, Louisiana, Virginia, and probably several other States.

ECONOMIC IMPORTANCE

It is difficult to obtain definite information concerning the actual losses caused by this disease. The occurrence and the severity of the disease where early cabbage is grown are not uniform, thereby making estimates of actual seedling losses impossible. A severe outbreak is especially disastrous to the grower of large acreages because of the large number of plants (approximately 10,000) required to plant an acre. A total or partial loss of the seedlings with the season far advanced results in a reduced acreage, as there is but slight possibility of obtaining enough seedlings from neighboring growers to replace those that are killed. To forestall such an emergency a much larger number of seedlings are grown than would otherwise be required. It is evident that this requires much additional time and greenhouse space.

In 1920 the writer endeavored to arrive at some more definite conclusions concerning the actual losses caused by this disease. Counting more than 1000 plants on each of three farms, immediately before transplanting into the field, it was found that 55 per cent of the seedlings were healthy, while 23 per cent were slightly diseased, and 22 per cent were severely diseased. This arbitrary classification of the diseased plants was made from the standpoint of the grower, who normally sets the slightly diseased plants and discards those designated as severely diseased. Some of the growers were of the opinion that slightly diseased plants which had apparently recovered could be transplanted into the field without any subsequent losses. To demonstrate that permanent injury had resulted to the seedlings, several hundred of each of the above classes of plants (healthy, slightly diseased, and severely diseased) were planted in adjacent rows on each of two farms. Careful records were kept of the number of heads and the pounds produced by each class. It was estimated that the actual losses on the two farms, considering the healthy plants as yielding normally, were 12 per cent in heads and 10 per cent in pounds for the slightly diseased plants, and 36 per cent in heads and 30 per cent in pounds for the severely diseased plants. If, then, of the 10,000 plants required to plant an acre, 23 per cent (2300 plants) were slightly diseased, the actual decrease in yield in heads (12 per cent) from this class only was 276 per acre. Accepting five cents a head as the average selling price, the loss per acre was approximately $14. This is a loss of which most growers are probably not aware. In addition to this loss and that of the discarded plants, there is also a loss caused by a delay in maturing of heads produced by the diseased plants. This loss is dependent on the fluctuations of the market, and may assume rather extensive proportions. This is especially true in a season with an early market. In 1920 there was an excessive amount of rainfall throughout the growing season, and this is probably the reason why there were only slight indications of delay in maturing. The following year an attempt was made to duplicate the above experiments, but the disease was not severe on any of the farms. On one, however, 32 per cent of the plants were found to be very slightly affected. Several hundred of these were planted, as before. Because of the only slightly diseased condition of the seedlings, the results of the harvest did not demonstrate any actual loss in yield, but a definite delay of a week or ten days in the ripening of the heads was very evident.

SYMPTOMS

Wire stem of cabbage is first evident as a typical damping-off. Usually the disease is to be observed when the seedlings are an inch or two in height. A water-soaked area completely encircling the tender stems is found just at the surface of the soil. In a few hours the stem loses its supporting power and the plant topples over. This occurs especially where the soil

is heavily infected with the causal organism. Under these conditions germination of the seed may be prevented, or the plants may be killed outright, but usually most of them will recover partially. In light attacks there may be no toppling over. If the moisture content of the soil is high, the plants may not even wilt. In a very few days, the cortex will be destroyed partially or completely and the second stage of the disease, wire stem, will be evident. Now is to be found a crooked, dwarfed plant with a peculiar tough, woody, wire-like stem (Plate I). Small brownish lesions, similar to those caused by this fungus on potato stems, are seldom found, but usually the entire basal part of the stem is affected. In the earlier, or damping-off, stage, the mycelium of the fungus is easily demonstrated at the margin of the lesion. When the wire-stem stage has appeared, it is often impossible to do this especially in the later period of the disease.

ETIOLOGY

Nomenclature, and review of literature

The disease under consideration is caused by *Corticium vagum* B. & C. The Corticium stage of this fungus was first recorded by Rolfs (1903, 1904). Judged by its parasitic mode of life and morphology, it was considered sufficiently different from *Corticium vagum* B. & C. to constitute a new variety and was designated *Corticium vagum* var. *solani* Burt. Burt (1918) later identified the Corticium causing the potato disease as the common *Corticium vagum* B. & C., thus reducing the variety to synonymy. Duggar (1915, 1916) reviews extensively the early European literature, and concludes that the fungus causing damping-off in this country is the same as *Rhizoctonia solani* Kühn, which causes lesions on potato stems in Europe. He states that the fungus is distributed throughout the United States, Canada, and Europe, has been reported from Brazil, France, Ireland, Australia, Great Britain, New Zealand, and Japan, and probably has been observed in all its stages in the more humid regions of India. Peltier (1916) gives an extensive table, setting forth the distribution of the disease and its many scores of hosts in the United States and other countries. Matsumoto (1921) was concerned chiefly with specialization of *Corticium vagum*, both in his review of literature and in his researches. This phase is discussed later in this paper.

Morphology and physiology

The mycelium

The mycelium of the fungus causing wire stem of cabbage is, both within the host and in culture, the typical, septate, broad, hyaline, branching "sterile fungus" mycelium which Atkinson (1895), Rolfs (1902, 1904), and others have accurately described. The diameter of the hyphae as computed by measuring fifty strands of a five-days-old culture is approxi-

mately 8.5 microns. This measurement was compared with others similarly obtained from six strains[7] of the same age, isolated from potato tubers and grown on the same medium.[8] No difference in size was observed (table 1).

The strain used throughout this work was isolated from a cabbage seedling in 1920. In 1923 lettuce seedlings were inoculated with this

TABLE 1. MEASUREMENTS OF HYPHAE AND SCLEROTIAL CELLS, IN MICRONS, OF DIFFERENT STRAINS OF CORTICIUM VAGUM B. & C.

Strain	Culture		Average diameter of mycelium (microns)	Dimensions of sclerotial cells (in microns)		
				Extremes		Average size
	Age	Source		Width	Length	
Cabbage	3 years	Seedling	8.5	16–28	22–38	19×30
Cabbage	1 month	Seedling	8.8	16–26	22–39	20×29
Potato 27	1 month	Tuber	8.5	16–30	22–41	23×31
Potato 49	1 month	Tuber	8.6	16–30	22–36	20×29
Potato 13	1 month	Tuber	8.8	15–27	24–44	22×32
Potato 70	1 month	Tuber	9.2	13–24	22–41	20×33
Potato 55	1 month	Tuber	9.3	16–30	23–43	23×32
Potato 51	1 month	Tuber	9.5	16–30	22–41	22×29
Aster	4 months	Seedling	6.2	10–20	15–24	14×19
Bamboo	1 year	Bud	7.3	8–13	14–24	11×19

strain, and the fungus was reisolated. The average diameter of the hyphae of the fungus more recently isolated was not different from that of the fungus grown on potato agar for over two years. Comparisons were made also of the diameters of hyphae of strains from cabbage, bamboo, and aster plants. The hyphae of the last two were consistently of smaller diameter (table 1).

The sclerotial cells

The barrel-shaped sclerotial cells so characteristic of *Corticium vagum* were present in abundance in seven-days-old cultures on potato agar (pH adjusted to 5.6). Comparisons of the average length and width of fifty of these cells were made of the strains mentioned above. Again the only differences in size were found in the consistently smaller cells of the strains from the bamboo and aster plants (table 1). The indications

[7] The term *strains* is used to designate isolations from different sources, as different tubers, different hosts, and so forth.

[8] The following formula was used in the preparation of the medium: pared potatoes, 200 grams; dextrose, 10 grams; agar, 20 grams; tap water, 1000 cubic centimeters.

were also that the cells of these two strains were different in shape, but the extreme variation in any one of the strains makes it impossible to state with certainty that this was uniformly the case. Daily microscopical examination of the cultures (potato agar) up to the seventh day revealed the fact that the sclerotial-cell formation was considerably slower in the strain from aster, and still slower in the strains from bamboo and cabbage, than in any of the strains from potatoes. In the strains from potatoes the rate of this formation was about uniform.

The fruiting stage

Two forms of hyphal growth similar to those described by Rolfs (1904) were frequently associated with wire stem. The light, hyaline form was usually found within the cortical tissue of the plant attacked. Frequently the dark form was found growing about the base of the seedling. With the potato strains, on potatoes, this was especially noticeable. In the inoculation experiments on potatoes, a large proportion of the stems were covered with this dark, weblike mycelium. An unsuccessful attempt was made to bring this mycelium into fruiting by placing the plants under bell glasses. With the cabbage strain, on crucifers, this mycelium was also very prevalent. The typical, white, granular, fruiting layer appeared frequently on the small stems of the cabbage, turnip, and radish seedlings, but it was only in one case, on turnips, that the basidia, with the sterigmata and the spores, were actually demonstrated. Several basidia, but only two spores, were observed. This limited number of fruiting structures is not regarded as sufficient to identify the organism, but from the measurements and general appearance they were considered identical with those described by Rolfs for the perfect stage of *Corticium vagum*. At no time in the numerous inoculations made was this "fruiting" mycelium from the potato strains observed on the cabbage seedlings, or that of the cabbage strain on the potato stems.

The temperature range for growth

Accurately controlled temperature chambers were available for only the higher temperatures. A fair idea concerning the minimum temperature for growth was obtained by placing petri-dish cultures in the bottom of a refrigerator where the temperature limits were about 9° to 11° C. Other cultures were placed in about the center of the refrigerator, where the temperature limits were approximately three degrees higher, and still others at the top, where the fluctuation was somewhere between 14° and 16° C. Another set of petri-dish cultures was held at room temperature, and others in controlled temperature chambers. The minimum and maximum temperatures for growth were found to be approximately 9° and 31° C. The optimum is not sharply defined, but is somewhere between

22° and 26° C. (table 2). The figures given in the table represent the averages of three trials.

TABLE 2. COMPARISON OF GROWTH OF HYPHAE OF THE CABBAGE STRAIN OF CORTICIUM VAGUM AT DIFFERENT TEMPERATURES, THREE DAYS AFTER BEING TRANSFERRED

Temperature (centigrade)	9°–11°	11°–14°	14°–16°	17°–23°	21.5°	22.5°	25.5°	27.0°	28.0°	29.0°	32.0°
Growth (centimeters)	0.5	1.3	3.0	4.0	6.3	7.0	8.0	6.0	3.5	1.2	0.5

The pH range for growth

The relation of the growth of the fungus to the hydrogen-ion concentration in culture was determined by making transfers from a young culture to petri dishes containing a freshly made medium adjusted to the desired acidity or alkalinity, and measuring the diameter of the area covered after five days of growth. Exactly 200 cubic centimeters of freshly prepared potato agar was placed in flasks. The proper number of drops of M/5 HCl or M/5 NaOH to produce the desired pH in each flask, as determined roughly by a preliminary trial, were placed in test tubes plugged with cotton. One tube was prepared for each flask. Where only a few drops were to be added to the medium, about 5 cubic centimeters of distilled water was placed in the tube to facilitate the delivery of the reagent from the tube to the flask. Several tubes containing 10 drops of either the acid or the alkali were also prepared as reserve tubes. In case the original amounts of reagent added did not produce the desired hydrogen-ion concentration, these known amounts were added to the partially adjusted media while it was still warm, without unnecessary delay or reheating. Both flasks and tubes were autoclaved for fifteen minutes at 15 pounds pressure. Without being permitted to solidify, the medium of each flask was adjusted by pouring into it the reagent from the corresponding tube and the pH was determined. In other trials, in which it was impossible to complete the adjustment for lack of time, the medium was not adjusted at the time of sterilization, but was allowed to cool and was reheated when the entire operation could be completed. The purpose of this was to eliminate complications which would result from intervening cooling and heating. The pH determination was made colorimetrically, with buffer mixtures,[9] and with the aid of a comparator block.[10] Several samples of 5 cubic centimeters each were poured (not pipetted) into test tubes, allowed to cool, and compared with the standard

[9] Clark, W. Mansfield. The determination of hydrogen ions, p. 1–317. 1920.

[10] Gillespie, Louis. Colorimetric determination of titration curves without buffer mixtures. Amer. Chem. Soc. Journ. 42:742–748. 1920. *Also*, Colorimetric determination of hydrogen-ion concentration without buffer mixtures, with especial reference to soils. Soil sci. 9:115–136. 1920.

indicators previously prepared. The medium of each flask was poured into petri dishes before the adjustment of the next flask was begun. This method is particularly satisfactory because the dangers of contamination are reduced to a minimum, and because it permits large numbers of replications on media of exactly the same pH value.

In a preliminary experiment performed as described, with the exception that lactic instead of hydrochloric acid was used for acidification, it was demonstrated that the minimum and maximum pH values for four different strains of the fungus were beyond 2.4 and 8.5, respectively. The optimum was not sharply defined. Considerable variation was in evidence, both within each strain and between the different strains.

In a subsequent experiment the same strains were compared, and the above-mentioned aster strain also was included. Considerable variation, due to some unexplained factors, again resulted. This experiment, however, clearly demonstrated that the maximum and the minimum were a little above and a little below pH 10.0 and 2.4, respectively. Again the optimum was not sharply defined.

In a third trial, both the old 1920 culture and the freshly isolated 1923 culture of the cabbage strain were compared with the aster, the bamboo, and the six potato strains. In this experiment the acid limit was reached for all the strains, but for neither strain was the alkaline limit definitely demonstrated (table 3). The rate of growth for the cabbage strain at the different pH values for five days is illustrated in Plate II. Considerable variation was again exhibited by the same strains at the different values. In general, the growth rate increased with an increase in pH up to a definite value, but rather frequently a plate of higher pH would show less growth than the one immediately below (table 3). A more sharply defined difference, however, was that of the tolerance of the various strains to acid media. The strain from bamboo was definitely more tolerant than any of the others, as it produced a mycelial growth one centimeter in diameter in four days at pH 2.0. The strains from potato tubers produced less growth, consistently, than either the cabbage, the bamboo, or the aster strain at this hydrogen-ion concentration (table 3). The color of the mycelium at these high acidities was white, so that it is not evident in the photographs of the petri dishes. By comparing table 4 and Plate III, it will be observed that at pH 2.4, the mycelium of both the cabbage and the aster strain completely covered the petri dish in twelve days. The potato strain (P 27) had covered an area of small diameter, almost completely covered with sclerotia, while the bamboo strain was a fluffy mass of white mycelium with minute sclerotia scattered over the surface of the petri dish (Plate III). At a pH of 2.7, similar results were again obtained. Here one of the potato strains (P 70) had covered an area of only 2.6 centimeters in diameter, while practically all of the other strains had covered the petri dishes (Plate IV).

TABLE 3. RATE OF MYCELIAL GROWTH OF CABBAGE, BAMBOO, ASTER, AND SIX POTATO STRAINS, OF CORTICIUM VAGUM ON MEDIA ADJUSTED TO DIFFERENT pH VALUES

Drops of reagent per 200 cubic centimeters of medium	pH	Growth, in centimeters, after four days									
		Strains*									
M/5 HCl		C 1920	C 1923	P 27	P 49	P 13	P 70	P 55	P 51	B	A
900	2 0	0 0	0 0	0 0	0 0	0 0	0 0	0.0	0 0	1.0	0 0
630	2.4	1.3	1.4	0.3	0.5	0.3	0.1	0.2	0.0	2.0	2.4
500	2 7	2 0	4 0	1.3	2 2	0 8	2 6	2.7	0.3	4 0	4.3
380	3.0	2.6	4.4	1.4	3.5	0.9	3.0	2.0	0.3	4.0	4.0
240	3.6	4.2	5.2	4.4	4.0	0.4	4.0	5.0	2.0	4.3	4.2
110	4.4	6.0	6.6	6.3	4 2	0 5	6.0	6.9	6.0	6.9	6.1
44	4.7	6.6	7.6	6.5	6.0	7.4	6.6	6.9	4.4	8.0	7.8
33	5.2	6.9	7.8	6.5	7.0	6.6	5.0	7.0	4.5	7.4	8.5
0	5.6	6.0	8.5	6.6	7.0	7.8	5.0	8.0	5.0	8.4	8.0
10	5 8	7.0	8.5		7 0	5 8	6.0	7.4	4.5	7.8	8.5
20	6.2	7.8	8.7	7.4	7.0	6.5	7.0	6.0	5.0	8.0	7.5
30	6.8	7 2	8 6	7 9	7 0	5 6	6.2	4.0	4.0	8.2	8.5
45	7.2	6.2	8.5	7.7	6.5	5.8	8.0	5.6	3.8	8.0	8.5
95	8.2	6.0	7.8	7.5	6.4	4.7	3.6	...	5.6	7.5	8.4
120	8.8	4.2	8.0	4.4	6.3	5.0	6.5	6.4	4.6	6.4	5.4
150	9.2	4 1	6 5	3 0	6 2	5.6	4 0	5 6	4.0	4.6	3.4
190	9.8	3.5	6.2	6.0	6.0	6.0	4.0	6.6	3.3	4.0	2.9
250	10.0	3.6	5.3	5.3	6.0	5.2	6.0	6.0	3.7	3.0	1.6
300	10.4	2.2	4 5	5 2	6 0	5 0	6 0	7 4	3.0	2.9	0.3
M/5 NaOH											

* C 1920, original strain from cabbage seedling.
C 1923, original strain reisolated from lettuce seedling.
P 27, strain isolated from potato tuber, from Elba, New York.
P 49, strain isolated from potato tuber, source unknown.
P 13, strain isolated from potato tuber, from Maine.
P 70, strain isolated from potato tuber, from college farms.
P 55, strain isolated from potato tuber, from college farms.
P 51, strain isolated from potato tuber, from college farms.
B, strain causing a bamboo bud rot in Bermuda.
A, strain isolated from aster seedling in college greenhouse.

The production of sclerotia in culture

The strains of the fungus at a pH of 2.7 exhibited a variation in the rate of formation of sclerotia as indicated in tables 4 and 5 and in Plate IV. There had been no indications previously, when they were grown in test tubes, that the several strains would produce sclerotia at a different rate; but when this comparative study was made, entirely different responses were noted in all three trials. The data in table 5 indicate the rate of

sclerotia formation at the various pH values for the different strains. This is further illustrated in Plate V. The potato strain, typical for all six tested, is shown to be the most rapid, followed by the aster strain, while but very few minute sclerotia had been produced by the cabbage

TABLE 4. RATE OF GROWTH AND FORMATION OF SCLEROTIA OF STRAINS OF CORTICIUM VAGUM AFTER TWELVE DAYS, ON VARIOUS ACID MEDIA *

Drops of reagent per 200 cubic centimeters of medium	pH	Strains †									
M/5 HCl		C 1920	C 1923	P 27	P 49	P 13	P 70	P 55	P 51	B	A
900	2.0	0	0	0	0	0	0	0	0	1.7 w	0
630	2.4	7.4 w	7.6 w	1.6 w	0.4 w	2.5 w	0.8 w	2.4 w	0.2 w	C w	8.5 w
500	2.7	C w	C w	C s w	C w	C w	2.6 s w	C s w	7.0 s w	C w	C w
380	3.0	C w	C w	C s w	C w	C s w	3.0 s w	C s w	8.5 s w	C b	C w
240	3.6	C w	C w	C s b	C s b	C s B	C s b	C s b	C s b	C b	C w
110	4.5	C b	C b	C s B	C s B	C s B	C s b	C s B	C s b	C b	C s b
44	4.7	C b	C b	C s B	C s B	C s B	C s B	C s B	C s B	C B	C s b
33	5.2	C b	C b	C s B	C s B	C s B	C s B	C s B	C s B	C B	C s b

* b, mycelium brownish in color; B, mycelium a deep brown; w, mycelium white; s, sclerotia present; C, entire plate covered with mycelium; numerals denote actual diameter, in centimeters, of the area covered with mycelium.
† Sources of strains as in table 3.

and bamboo strains. This was consistent for each of the seventeen petri dishes per strain, where sclerotia were produced. Another sharply defined difference was noticed between the sclerotia of the different potato strains themselves, namely, in the habit of their formation in the petri dishes (Plate VI). Those produced by strain P 13 were uniformly scattered

over the surface and were cinnamon brown in color. Strain P 70 produced large, uneven, irregular, ridge-like, grayish brown masses extending outward from the center of the dish. Strain P 27 formed blackish brown, closely compacted masses in the center of the petri dish.

TABLE 5. RATE OF FORMATION OF SCLEROTIA OF DIFFERENT STRAINS OF CORTICIUM VAGUM ON MEDIA ADJUSTED TO DIFFERENT pH VALUES

Drops of reagent per 200 cubic centimeters of medium	pH	Number of days after transfer of the culture									
M/5 HCl		C 1920*†	C 1923*	P 27	P 49	P 13	P 70	P 55	P 51	B *	A
900	2.0	0	0	0	0	0	0	0	0	0	0
630	2.4	0	0	12	0	0	10	0	0	0	0
500	2.7	0	0	10	12	9	6	7	10	0	0
380	3.0	0	0	10	12	9	6	7	9	0	0
240	3.6	0	0	10	12	6	5	6	8	0	12
110	4.4	0	0	8	9	5	5	5	7	0	11
44	4.7	0	0	5	8	5	5	5	7	0	11
33	5.2	0	0	5	8	5	5	5	7	0	11
0	5.6	0	0	5	8	5	5	5	7	0	11
10	5.8	0	0	0	8	5	5	5	7	0	11
20	6.2	0	0	5	8	5	5	5	7	0	11
30	6.8	0	0	5	8	5	5	6	7	0	11
45	7.2	0	0	5	8	5	5	6	7	0	11
95	8.2	0	0	5	8	5	5	6	7	0	12
120	8.8	0	0	6	8	5	5	6	7	0	12
150	9.2	0	0	6	8	5	6	6	7	0	12
190	9.8	0	0	6	10	5	6	6	7	0	12
250	10.0	0	0	6	10	6	6	6	7	0	12
300	10.4	0	0	6	10	6	6	6	7	0	12
M/5 NaOH											

* Very few minute sclerotia were formed in two or three plates in the twelve days during which the observations were made.

† Sources of strains as in table 3.

The foregoing results are in accordance with the researches of Matsumoto (1921) and others in that they point to constant differences. Since minor variations in environmental conditions apparently cause such large variations in growth, it would seem futile to attempt to compare these strains with those of another investigator.

In addition to observing the growth rate of the mycelium in the temperature experiments (table 2), the rate of sclerotia formation was also

noted. Twenty days after the cultures had been transferred, the petri dishes at the intermediate temperatures were practically covered with sclerotia. Only a few had appeared at the second and third lowest temperatures, and none at the lowest and the three highest temperatures.

Pathogenicity

Historical aspects

According to Duggar (1915), Eidam (1888) was probably the first to mention the ability of *Corticium vagum* to cause a seedling disease of small plants. The host mentioned was the beet (*Beta vulgaris* L.). No complete account was given to prove that this fungus was the causal organism. Atkinson (1895), by his careful description of the general characteristics of the mycelium, and by his observations on the "sclerotoid bodies" produced by his "sterile fungus," leaves no question as to the identity of the organism. He, however, did no culture work to demonstrate its pathogenicity. Duggar (1899) attributes the damping-off of the sugar beet in New York to this fungus. Fawcett (1909), basing his conclusions on the identification of the fungus by Orton, who declares it the same organism as that on potatoes, attributes the damping-off disease of cabbage to *Corticium vagum* because of its constant association with the host. Sherbakoff (1916) is apparently the only worker who has made any inoculations of cabbage or other cruciferous seedlings to demonstrate that *Corticium vagum* is capable of producing the disease in question.

Experimental data

The writer first observed wire stem in April, 1920, on plants which were being transplanted into the field. Very few of these plants had been killed by the fungus, but a large amount of wire stem was found. In order to determine the source of the inoculum for infection under natural conditions, seeds previously disinfected with a 1–1000 mercuric-chloride solution for twelve minutes were planted in flats in (a) virgin soil from woods, (b) untreated soil from the greenhouse in which diseased plants had been grown, (c) soil from the greenhouse in which diseased plants had been grown and treated with either steam or formaldehyde. Several hundred plants were grown in each of these different soils. All of the plants in the virgin soil remained healthy, while all of those in the untreated greenhouse soil showed wire stem. Only a few plants in the treated greenhouse soil were affected. These results indicated that the soil carried the inoculum. Germination was greatly reduced in the infected soil, and an examination of the seed showed that many of the sprouts had emerged a millimeter or so and were then killed. Damping-off was noticed first. Within approximately ten days the plants that had not been killed outright developed wire stem. Later experiments confirmed these indications that the inoculum was harbored in the soil.

Finely chopped stems of diseased seedlings were next thoroughly mixed into virgin soil, and untreated seed was sown. Virgin soil not containing the diseased stems, and soil in which diseased plants had been growing, were used for comparison. The seed in the first flat germinated poorly. Most of the plants were killed outright, and the remainder developed wire stem. The seed in the fungus-infected greenhouse soil gave normal germination and considerable damping-off, followed by the wire-stem stage. The seed in the clean soil produced no diseased plants. This experiment indicates that parts of diseased plants may harbor the pathogene, that the fungus is not carried in the seed, and that the amount of inoculum in the soil is a factor in determining whether the plants will be killed outright or will develop wire stem only.

Diseased stems were next examined, and the typical, broad, hyaline mycelium of *Corticium vagum* was demonstrated in the outer tissues of the plant. Hundreds of tissue plantings from diseased stems were made on potato agar, and the fungus was consistently isolated throughout the summer.

In the winter of 1921, soil-infection experiments with pure cultures of the fungus were conducted, and the results obtained were conclusive in establishing the pathogenicity of the fungus. In addition, these experiments developed the most satisfactory method of inoculation. This method consisted in growing the fungus on sterilized wheat in wide-mouthed bottles, adding a kernel of this substrate to the base of the seedling, and covering slightly with soil. This procedure was followed exclusively in all of the later experiments unless otherwise stated. In the early experiments the inoculum was added to the soil directly, but this method was not satisfactory for wire-stem investigations as the number of plants pushing through the surface of the soil was greatly decreased.

In these early experiments the inoculum was added to thirty-six 4-inch pots of sterilized soil as follows: growing on potato agar, six pots; growing on wheat, fifteen pots; growing on soil-cornmeal mixture, fifteen pots. Six pots were maintained as controls. Twelve treated seeds per pot were sown immediately after the inoculum was added to the soil. In the infected soil, germination and growth were very poor. In the controls, all of the seed germinated and the plants remained healthy. The check plants were inoculated later by adding the inoculum to the base of the stems, and all of them developed the disease. Isolations were made, and *Corticium vagum* and a species of Fusarium were obtained. In later inoculations only the former fungus produced the disease. Many such inoculations and reisolations in the past two years have removed all possibilities of doubt concerning the pathogenicity of this particular strain.

Inoculation experiments

Susceptibility of different varieties of Brassica oleracea L.

"All Seasons" was the variety of cabbage used in all of the preceding as well as the following experiments. Six early, nine late, four red, and three savoy varieties also were tested, and in addition five varieties of kale, four varieties of cauliflower, and one of brussels sprouts. None showed any degree of resistance. When the few plants that did not exhibit wire stem at the first count were reinoculated by placing some infected soil directly about the stems, damping-off occurred in every instance within twenty-four to forty-eight hours. After the observations were made, the checks were likewise inoculated, with similar results. Thus a total of about 250 seedlings of each variety were tested.

Susceptibility of other species of plants

The strain from cabbage was found to be pathogenic on eleven of the thirteen hosts inoculated (table 6). These hosts represent eleven species,

TABLE 6. RESULTS OF INOCULATION OF DIFFERENT HOSTS WITH THE STRAIN OF CORTICIUM VAGUM FROM CABBAGE

Family	Genus	Species	Common name	Number of pots	Number of plants	Per cent of disease*	Severity*
Cruciferae	Brassica	rapa L.	Turnip	5	100	80 d	.....
Cruciferae	Raphanus	sativus L.	Radish	5	150	90 d	.....
Chenopodiaceae	Beta	vulgaris L.	Beet	5	300	86 d	.....
Leguminosae	Trifolium	pratense L.	Red clover	5	200	10 l	+
Leguminosae	Medicago	sativa L.	Alfalfa	5	300	17 l	+
Leguminosae	Vicia	sativa L.	Vetch	5	150	8 l	+
Leguminosae	Phaseolus	vulgaris L.	Bean	5	100	20 l	+
Liliaceae	Allium	cepa L.	Onion	5	50	0	.....
Solanaceae	Solanum	melongena L.	Eggplant	5	100	30 l	++
Solanaceae	Solanum	tuberosum L.	Potato	65	65	0	.....
Malvaceae	Gossypium	herbaceum L.	Cotton	5	50	20 l	++
Compositae	Arctium	minus Bernh.	Burdock	1	40	50 d	.....
Compositae	Lactuca	sativa L.	Lettuce	2	120	80 d	.....

* d, damping-off; l, stem lesions; +, very slight; ++, definite.

eleven genera, and six families. No infection resulted when onion seedlings or potato stems were inoculated.

Susceptibility of plants of different ages

It is generally held that tender, succulent seedlings are very susceptible to damping-off, and that as the plants grow older this susceptibility gradually decreases. It is supposed that as the tissues become harder and older there is reached a stage of maturity after which the stems are practically immune. In order to obtain information on this point, seed was sown in sterilized soil at intervals of two weeks, and the plants were

inoculated when the oldest had been growing for twenty weeks. No lesions were obtained on plants of that age, but very definite lesions were produced on those eighteen weeks old and younger (Plate VII). It is evident that the susceptibility gradually decreases with the age of the plant. Many of the lesions on plants over twelve weeks old were not typical for wire stem but were chiefly confined to a part of the stem only. A growing period of twenty weeks in the field is practically long enough to grow the early varieties to maturity. The variety used here, the late "All Seasons," requires a longer time for maturing.

Biologic specialization

Review of literature

It is a matter of common knowledge that *Corticium vagum* is parasitic on a wide range of host plants. The reader is referred to articles by Duggar (1915) and Peltier (1916) for comprehensive reviews of the literature on this phase of the subject.

Since the fungus is so widely distributed and occurs on such a great number of hosts, the question of strains may well be considered. Occasional reports of the discovery of definite strains emphasize the possibility that important differences may exist within the species. Duggar and Stewart (1901) early recognized the possibility of the existence of species or strains of the fungus, and conducted cross-inoculation work. They discontinued their experiments, however, before any definite conclusions were reached. Shaw (1912) isolated *Corticium vagum* from peanuts, cowpeas, jute, and cotton, and concluded from cross-inoculations that the organism from jute is restricted to that particular host. Duggar (1915), after a rather extensive study of the diseases caused by *Corticium vagum*, came to the conclusion that, while many of the strains from different hosts exhibit minor modifications, only that from rhubarb is of specific importance. He mentions the occurrence of strains, the evidence of which persisted for some time in the general appearance of the cultures. He also gives a brief statement concerning the variation in size of sclerotia, from the minute, scarcely visible ones, to those a centimeter or two in diameter.

In their publications in 1916, Duggar, Peltier, and Sherbakoff discussed the possibility of specialization. Duggar concluded that the common seedbed fungus in Germany and France is identical with the damping-off fungus which has frequently been observed since the investigations of Atkinson, and, further, that the damping-off fungus of this country is *Rhizoctonia solani* Kühn (*Corticium vagum* B. & C.). Peltier conducted extensive researches which included symptom studies; inoculation experiments involving comparisons of forty-five strains of the fungus on approximately 3000 cuttings, 2000 plants, and 7000 seedlings of various sorts; observations on artificial media; measurements of mycelial cells;

and soil surveys. He concluded from these experiments that all the strains studied by him were the same. These strains were obtained from a wide range of hosts from different parts of the country. Peltier observed no marked specialization in any of them. He did note, however, that the virulence of the fungus was extremely variable, as was also the degree of resistance of the various hosts. Growing the strains on artificial media, he observed much variation, those from the same host often producing different growth on the same substratum. However, the variations in cultural characteristics exhibited by isolations from different hosts were no greater than those manifested by two strains from the same host or by the same strain at different ages. Again, he could find no standard for distinguishing the different strains by means of mycelial cell measurements, because of the extreme variation in size even in the different isolations from the same host. Sherbakoff isolated *Corticium vagum* from more than fifteen hosts. He used eight strains, isolated from lettuce, castor bean, amaranthus, watermelon, cowpea, the pods of the garden bean and the velvet bean, and tomato fruit, and one culture received from Duggar, to inoculate seedlings of lettuce, celery, eggplant, pepper, and tomato. He found some strains pathogenic on cabbage, cauliflower, cucumber, garden bean, and other hosts, but it is not clear whether the fungus from potato was included in these. He concludes that the strains are morphologically alike, but makes no mention of any specialization in pathogenicity.

Rosenbaum and Shapovalov (1917), however, reported the isolation of a strain from potato which can be distinguished from the common form by the more pronounced lesions made when the strain is inoculated on injured stems or tubers; by the reaction, growth, and character of sclerotia on artificial media; and morphologically, by measurement of the diameter of germ tubes when the short, or "barrel-shaped," cells, enveloping the sclerotia, are placed in drops of water to germinate.

Edson and Shapovalov (1918) reported extreme variation in pathogenicity of the *Corticium vagum* strains used, from those absolutely unable to attack any underground parts to those which produced large and deep cankers. Also, not only were the size and the depth of the lesions consistently unlike, but their color and shape were consistently rather peculiar to certain individual strains. These investigators found that the strains in no way had become attenuated by reason of growth on artificial media for long periods. One in particular was very aggressive, being strongly parasitic on tomatoes and sugar beets, both as a damping-off fungus and in producing a root rot of adult plants.

Finally, the work of Matsumoto (1921), which is the most comprehensive and the most recent, must be considered. Fifteen isolations were obtained from different localities, from potato, lettuce, eggplant, *Habenaria* sp., and navy bean, and one from an unknown source. These were studied

comparatively. From a macroscopic and microscopic examination some of them could apparently be identified conclusively, so that only six different types remained for physiological studies. All strains could hydrolyze starch and invert cane sugar. All showed increased growth at a pH lower than 7.0, and all grew abundantly at 3.8. Four of the six strains exhibited different minimum, optimum, and maximum temperatures for growth. Their diastatic activity was unlike, and there was a striking difference in the conversion of cane sugar. There were indications of differences in the cellulase activity of the different strains. A difference in the growth on casein, on peptone, and on asparagin was noted. Only two strains could utilize potassium nitrite. All strains exhibited different acid ranges. Fusion of hyphae was observed between some strains only, and a striking difference in virulence was observed. It was noted that greatest virulence was always manifest when inoculation was made on plants belonging to the same host as that from which the culture originated. Matsumoto concluded that there is a definite specialization among the strains tried, but that all are forms of *Rhizoctonia solani* Kühn except one, which may have exhibited sufficient differences to be considered of specific rank. This had been isolated from potato.

Reviewing, then, the whole problem in the light of these investigations, it is evident that the questions of biologic specialization needs further study. It might be of value to observe here that of the investigators who actually performed cross-inoculation experiments (Shaw, Sherbakoff, Peltier, Edson and Shapovalov, and Matsumoto), none, according to the evidence at hand, have inoculated cabbage seedlings with potato strains, or have used the cabbage strain to inoculate potato plants. Sherbakoff (1917a), working with but one strain from potato, may have conducted such cross-inoculations, as he states that some strains were tried on cabbage, cauliflower, cucumber, garden beans, and other plants, and proved able to produce damping-off.

Experimental data

Early in his experimental work, the writer found indications of the existence of specialization in the strains which he was using. In the spring of 1921, twelve cabbage seeds were sown in each of twenty-seven 4-inch pots of sterilized soil. When the seedlings were two inches high, they were inoculated by placing a bit of potato agar containing mycelium at the base of the stem and covering lightly with soil. The plants in six of the pots were inoculated with a strain from cabbage isolated the previous summer; those in six others, with another culture isolated at the same time; those in a third group of six, with a strain from potatoes from Canada; and those in a similar group, with a strain from potatoes from Maine. The remaining pots were kept as controls. Both the cabbage strains produced 100 per cent damping-off and typical wire stem. Neither of the strains from potatoes produced the disease. The checks likewise

remained healthy. After ten days the inoculum was placed about the stems a second time, but again the plants remained healthy. Finally the cabbage strain was placed about the base of some of the seedlings, and all of these damped-off while the checks continued healthy.

The following June a similar experiment was performed in which twenty-two different strains of the fungus were tested. Twelve cabbage seeds were placed in each pot, and two pots were used for each strain. The strains were obtained as follows: thirteen isolated from as many different lots of potatoes obtained from New York, Minnesota, Maine, Canada, and some unknown sources; two from cabbage seedlings from western New York; one each from peas, peppers, eggplants, tulips, and grass; and two from unknown sources. Inoculations were made when the plants were two inches high. The cabbage, pea, pepper, and eggplant strains produced typical wire-stem lesions. All the others, including the checks, showed slight lesions, but these appeared to be a shriveling at the base rather than injury from fungus attack. When this experiment was performed, the temperature was abnormally high, and the possibility is that the high temperature, inadequate shading, and injudicious watering caused these peculiar atypical lesions. In this experiment the same Maine and Canada strains from potato which gave negative results in the previous experiment again produced no infection. The argument might be advanced that some of the strains were attenuated. While the exact date of isolation for some of them could not be determined, it is known positively that the cabbage, the eggplant, and some of the potato strains were of the same age.

In December, 1922, this experiment was repeated. As in the previous experiments, the exact length of time that the strains had been grown in culture was not determined, but most of them were of practically the same age. The cabbage strain, and some of the others also, were the same as those used in the preceding experiment. Five pots, each containing more than fifty plants, were used for each strain. The seed was sown in steam-sterilized soil, and the seedlings were inoculated when they were about two inches high. Here again the cabbage, pepper, pea, and eggplant strains produced typical wire-stem lesions, as did also the tomato, the salvia, and another strain of unknown origin (table 7). All of the plants inoculated with the potato and other strains, as well as the checks, remained healthy.

An experiment was then conducted to ascertain whether or not the strains from potato were pathogenic on potato. The soil of each strain from potato of the preceding experiment was mixed with an equal volume of sterilized soil. A tuber, or half of a tuber, of the Bliss Triumph variety, previously treated in a 1–1000 solution of corrosive sublimate for one and one-half hours, was placed in the bottom of each of ten pots, for each strain of the fungus. An additional amount of inoculum on wheat was

TABLE 7. RESULTS OF INOCULATIONS OF CABBAGE SEEDLINGS WITH DIFFERENT STRAINS OF CORTICIUM VAGUM

Strain	Source	Per cent of plants diseased
Pea	Wilson, New York	68
Lettuce	Williamson, New York	0
Potato	Unknown	0
Potato	Canada	0
Potato	Maine	0
Tomato	Eden, New York	74
Salvia	Eden, New York	78
Bamboo	Bermuda	0
Potato	Minnesota	0
Potato	Williamson, New York	0
Eggplant	Eden, New York	98
Unknown	Williamson, New York	0
Grass	Massachusetts	0
Unknown	Unknown	60
Pepper	Albany, New York	97
Cabbage	Eden, New York	98
Checks		0

added to the soil immediately surrounding the seed piece and a little above the upper surface of the tuber, so that any sprouts would pass directly through it. The pot was filled with the remaining soil. All the pots were kept in the same greenhouse where the previous experiment had been conducted. This house was comparatively cool, having a temperature of approximately 8° to 15° C. at night, and about 10° to 18° C. during the day. The soil was kept moderately moist, but no attempt was made to control accurately the moisture content. All the tubers sprouted. When they were from two to three inches high, many were removed from the soil and examined, but no lesions were observed on the stems. The plants were carefully replaced and allowed to grow for two and one-half months. At the end of that time they were removed from the soil, and the stems and rootlets were examined for lesions, and the new tubers and the seed pieces for sclerotia.

Parallel with this experiment, fifty tubers were placed in soil infected with the cabbage strain of the fungus. When the sprouts were two or three inches high, and no lesions were developing, ten plants were reinoculated just beneath the surface of the ground and these were kept in a moist chamber for forty-eight hours. They were then removed to the greenhouse bench. A little later, when the plants were from six to eight inches high, cabbage seed was sown around the base of twenty-five of the plants growing in the soil infected with the fungus from cabbage.

A large proportion of these seedlings developed typical wire stem. This demonstrated that the fungus was still in the soil and in an active condition. The tubers were harvested when they were from one to two inches in diameter. Very few definite lesions were produced even by the strains from potatoes, probably because of the unfavorably low temperature. The striking difference was in the occurrence of the sclerotia on both the old seed pieces and the new tubers, many sclerotia having been produced by the strains from potatoes, but none by the cabbage strain in any instance (table 8). None of the lesions reported in the table were very large,

TABLE 8. RESULTS OF INOCULATING POTATOES WITH DIFFERENT STRAINS OF CORTICIUM VAGUM

Number of pots	Strains	Lesions		Sclerotia *			Number of new tubers
		Roots	Stems	Roots	Seed pieces	Tubers	
10	Unknown	0	0	0	0	0	14
10	Potato	0	2	++	++++	++++	16†
10	Salvia	0	2	0	+++	0	14
10	Potato	2	0	0	0	0	19
10	Lettuce	0	0	0	0	0	12
10	Pepper	0	2	0	0	0	18
10	Potato	5	0	+	+++	+++	13†
10	Eggplant	2	0	0	+	0	15
10	Pea	3	0	0	+	0	12
10	Bamboo	0	0	0	0	0	15
10	Potato	0	2	0	+	+	15
10	Tomato	0	0	0	0	0	19
10	Unknown	0	0	0	+	0	15
10	Unknown	0	0	0	+++	0	16
10	Grass	0	0	0	0	0	15
40	Cabbage	0	0	0	0	0	100
10	Cabbage (stems inoculated twice)	0	0	0	0	0	25
10	Controls	0	0	0	0	0	21

* +, an occasional sclerotium, or very slight lesion; ++, few sclerotia, or rather definite lesions; +++, numerous sclerotia, or deep lesions; ++++, very many sclerotia, or several deep lesions.

† Stems of most of the tubers were covered with the weblike mycelial mat characteristic of *Corticium vagum*.

although all were typical. It is to be noted that every potato strain produced lesions, even though few in number, while only four of the other strains did so. Only the potato strains produced sclerotia on the new tubers and on the roots. With one or two exceptions the potato strains produced the most and the largest sclerotia on the cut surfaces of the seed pieces. The cabbage, tomato, grass, bamboo, and lettuce strains produced no signs nor symptoms of the disease on either the roots, the stems, or the tubers.

Two strains from potatoes (indicated by daggers in table 8) produced definite dark brown wefts of mycelium on the stems of the plants. Some of the pots were placed in a moist chamber, and some under bell glasses, with the hope that the perfect stage might be obtained, but these efforts were unsuccessful. It is to be noted (table 8) that these two strains produced definite lesions on either the stem or the roots, and also produced the most and the largest sclerotia on both the old seed pieces and the new tubers. It is worthy of note that of these two strains, the one producing the most lesions and sclerotia was the one which was isolated from the potatoes from Canada two years earlier and at that time demonstrated to be non-pathogenic on cabbage (page 19). Here, then, it is to be observed that the pathogenic cabbage strains produce neither lesions nor sclerotia on any part of the potato, but it is possible to get infection with them on cabbage under a wide range of conditions; also, that the strains from potatoes, non-pathogenic on cabbage, produce definite lesions and sclerotia in numbers on their own host.

Extensive inoculation experiments were next undertaken with freshly isolated potato strains to determine conclusively whether the differences in pathogenicity of the various strains were due to a specific relationship between host and parasite, or to other factors. From forty to fifty seeds of cabbage were sown in sterile soil in 4-inch pots. When the seedlings were two inches high, inoculations were made with forty-one freshly isolated strains from potatoes. Thirty-nine of these were obtained from sclerotia from five different lots of tubers from three different counties in New York, and two from different lots of southern potatoes bought at a retail store. Two pots were used for each strain. This experiment was repeated later in duplicate, as before, with twenty-two of the strains. Ten pots were reserved as checks in both trials. Every seedling was observed, and eight slightly discolored stems were found in the first trial. This, however, was a discoloration only and not a case of wire stem or damping-off. In the second trial, all of the seedlings in one pot damped-off, as did also five others in each of two other pots. This damping-off was evidently a result of improper sterilization of the soil, since no diseased plants were produced in any of the duplicates in the above series, and since twelve pots of seedlings had to be discarded before the inoculations were made. The seedlings in five of the controls developed the disease later. The plants in four pots in each of these trials were inoculated with the cabbage strain, and practically 100 per cent of infection resulted in every case. All of the checks remained healthy except where the soil was not properly sterilized. From these data, where from 35 to 50 seedlings were inoculated in each of 125 pots, or a total of from 4500 to 5000, with negative results, the conclusion is warranted that the freshly isolated potato strains are not pathogenic on cabbage.

Parallel with the preceding experiment, a strain of *Corticium vagum* isolated from asters in December, 1922, at the college greenhouse,

was used to inoculate cabbage seedlings at different times. Negative results were consistently obtained. The cabbage strain under the same conditions produced 100 per cent of damping-off, and the checks remained healthy. To further test this particular strain, seedlings were inoculated as follows: two rows on one end of a flat were inoculated with the cabbage strain, and two rows on the other end with the aster strain. The three rows at the center served as controls. The center rows and those inoculated with the aster strain remained healthy. Of the plants inoculated with the cabbage strain, 80 per cent damped-off. Therefore the aster strain tested here is not pathogenic on cabbage. Inoculations on asters at this time demonstrated that the strain is pathogenic on that host.

In a study of the question as to whether or not the strains freshly isolated from potato tubers are pathogenic on potatoes, the following experiments were performed. Tubers of the Bliss Triumph variety, treated with corrosive sublimate as before, were planted in the temperature tanks (page 26,) where both the temperature and the moisture of the soil could be controlled. Richards' (1921, 1923) strain of *Corticium vagum* could infect potatoes at a wide range of temperature, 9° to 27° C., with the optimum near 18°. The optimum for the host was about 24° C. In view of these facts, the soil temperature was maintained at 22° in order to hasten germination but still remain within the range of infection. The moisture content of the soil was maintained at about two-thirds of its water-holding capacity. Sterilized soil in glazed earthenware gallon jars, measuring 19 by 19 centimeters, was used in all cases. One seed piece was placed in each jar, and five jars were used for each strain and twenty-five jars for each tank. One set of five jars was inoculated with the cabbage strain as a check on the previous experiment (table 8). The inoculum was placed around the seed piece and in the same plane as the upper surface of the tuber, to insure the contact of the sprout with the fungus. When the plants were three inches high, 70 per cent of all the stems inoculated with the potato strains had distinct lesions. All the strains tested were pathogenic, each producing lesions on from two to five of the five stems inoculated. Wounding and reinoculating the uninjured stems increased the total number of injured stems to 80 per cent. The initial inoculation with the cabbage strain gave negative results, and a reinoculation after wounding produced slight discoloration on three stems. It is not positive that this discoloration was caused by the fungus, as these lesions became no more pronounced after ten days. In a second tank, maintained at exactly the same temperature and moisture conditions, twenty-five tubers were inoculated with the cabbage strain as before. Here three stems developed small, superficial, apparently positive lesions, but these failed to develop further. All the stems, except the three mentioned, were wounded and a large amount of inoculum was pressed tightly against the wound, but no further lesions developed. Again, it is doubtful whether the cabbage strain caused these lesions. In a third tank, where the soil temperature

fluctuated between 15° and 19° C., twenty seed pieces were inoculated with potato strains and five with the cabbage strain. The sprouting of the tubers, as compared with those in the other tanks, was delayed a week or ten days because of the low temperature. For the same reason, the initial inoculation produced infection on only 25 per cent of the stems. Various methods of reinoculation were attempted, resulting in lesions on 65 per cent of the stems. No lesions were produced by the cabbage strain. In this trial many sclerotia were produced on the rootlets and even on the stems. Both the potato and the cabbage strains produced sclerotia in abundance on their respective hosts, but were never observed to do so on the opposite host. When the cabbage seedlings were inoculated with the potato strains, the soil and the base of the stems were frequently covered with the fungus mycelium, but neither sclerotia nor lesions were observed.

A total of 230 inoculations of potatoes were made with thirty-two strains of the fungus freshly isolated from potatoes, and nineteen of these strains were definitely pathogenic. The remaining thirteen likewise might have proved pathogenic had the temperature been more favorable. These negative results were obtained when the soil temperature fluctuated between 22° and 25° C., a temperature too high for the rapid development of the disease (Richards, 1923). This was demonstrated by inoculating potato stems at these higher temperatures with strains previously proved to be pathogenic. Under such conditions these likewise produced no lesions. Parallel with the above-mentioned inoculation experiments, sixty-five tubers were inoculated with the cabbage strain and placed under these controlled conditions. No definite lesions developed, demonstrating the non-pathogenicity of this strain on potatoes. In the light of the hundreds of inoculations on cabbage seedlings with the pathogenic strains isolated from potatoes, and the large number of inoculations on potatoes with the cabbage strain, all under more or less favorable conditions, it must be concluded that a specific pathogenicity exists.

Longevity of the fungus in the soil

Little is known concerning the actual length of time that this fungus will persist in the soil. Since it is parasitic on a considerable number of plants, the possibility is that it may live in the soil indefinitely. Further, the organism is saprophytic on the organic matter in the soil (Rolfs, 1902, 1904), and the richer the soil is in humus, the more favorable are the conditions for its development. When the investigations on this problem were discontinued at the approach of the summer season in 1921, the pots containing the fungus-infected soil were placed under the greenhouse benches and permitted to completely air-dry. The following fall this soil was thoroughly mixed and cabbage seed was planted in it. The same procedure was followed also with the soil that was used the second year. In both seasons the percentages of diseased plants were approxi-

mately as great as from naturally infected soil or from soil into which had been mixed an average amount of inoculum. The soil was left in this condition for about seven months. These conditions were probably more unfavorable than any field conditions would be, since no plants were growing in the soil, the temperature was abnormally high in the greenhouse, and the soil was practically free from moisture.

TEMPERATURE AND MOISTURE STUDIES

It is evident from the literature that temperature and moisture are important factors in the parasitism of this fungus. Johnson (1914), Peltier (1916), Sherbakoff (1917, b), and others suggest that damping-off in general is favored by wet soils and humid atmospheres, relatively high temperatures, and poor ventilation. Rolfs (1904) concluded from his laboratory investigations that a high temperature and plenty of moisture were essential for the development of *Corticium vagum*. He suggested that this may be the reason why heavily watered fields of potatoes may be severely injured in hot weather, while those sparingly watered and well cultivated are apparently not injured. Richards (1921, 1923) obtained infection within a temperature range of 9° to 27° C., with the optimum approximately at 18°. Considerable infection, however, was obtained at from 15° to 21°, depending on slight changes in environmental conditions.

Experimental methods and data

Temperature-moisture relations

Since no report was to be found in literature of researches to determine definitely the interrelationship of soil moistures, soil temperatures, and damping-off by *Corticium vagum*, some experiments in this connection were performed. The results of preliminary experiments were in accordance with the conclusions of Johnson (1914) and others who found that a combination of high soil moisture, high humidity, and poor ventilation, is favorable for the development of fungi which cause damping-off.

This phase of the problem was studied in controlled-temperature tanks. These tanks, as used by Burkholder,[11] were 4 feet square and 8 inches deep, and contained water the temperature of which was automatically controlled by electrical units. In the experiments conducted by the writer, a third tank, not electrically controlled, was thoroughly insulated with sawdust and cork and was used for the lower temperatures only. Several changes of cold water during the day aided in maintaining the desired temperature in this tank. The surface of all the tanks was covered with paraffined canvas, into which sixteen holes were cut at definite intervals to permit the immersion of ordinary glazed gallon jars (19 by 19 centimeters).

[11] Burkholder, Walter H. The effect of two soil temperatures on the yield and water relations of healthy and diseased bean plants. Ecology 1:113–123. 1920.

With this arrangement and good thermostats, it was possible to keep the temperature of the water bath constant so that an ordinary thermometer registered no variation for weeks at a time (figure 9, page 41). The temperature in the uncontrolled tank, if adjusted two or three times a day, would fluctuate within two or three degrees. Thermographs were installed in each tank. These, though fairly accurate, required considerable adjusting, and were not relied upon for temperature readings but were used to indicate changes in temperature only. The temperature of both the water bath and the soil in the culture vessels, as well as that of the air, was taken several times daily by means of thermometers. While the temperature of the water remained constant, it is evident that in an ordinary greenhouse the soil temperature nevertheless varies, depending on the intensity of the sunlight and the fluctuations of the air temperature. The greater the difference between the air temperature and the water temperature, the greater are the fluctuations in the soil temperature and the greater is the difference between the soil and the water temperature. For example, when it was desired to maintain the soil at 32° C., it was necessary to maintain the water at 35°, since the house was kept at approximately 10° to 15° C. at night and at about five to ten degrees warmer during the day. However, the air temperature was extremely variable, and bright sunlight would cause the soil in this tank to reach a temperature somewhere between 33° and 34° C. As soon as the direct rays of the sun were no longer on the culture vessels, the temperature would drop rapidly to approximately 32°. The limits were, however, never higher than as indicated in the tables, and usually were lower. The temperatures given in the tables are the maxima and minima taken in the upper half-inch of the soil, as this is the region most directly related to damping-off. Various measures, such as maintaining the surface of the soil an inch or more below the surface of the water, and planting the seedlings close to the sides of the jar, were taken to aid in keeping the temperature constant. With three tanks, three temperatures could be run simultaneously.

The moisture content of the soil, in all of these trials, was also controlled. Livingston auto-irrigators[12] were used, two in each jar. The maximum water-holding capacity of the soil was determined by the Hilgard 1-centimeter-column method.[13] Two series of moistures were maintained throughout the trials. In order to keep the moisture content of each culture vessel comparable with the others in any one moisture series, half of the culture vessels in one tank were connected with half of those in each of the other tanks, with but one intake valve for that series. The other halves of the jars in the respective tanks were similarly connected,

[12] Livingston, B. E. A method for controlling plant moisture. Plant world 11:39–40. 1908.
Hawkins, Lon A. The porous clay cup for automatic watering of plants. Plant world 13:220–227. 1910.
Livingston, B. E., and Hawkins, Lon A. The water-relation between plant and soil. Carnegie Inst. Wash. Publ. 204:3–48. 1915.

[13] Hilgard, E. W. Soils, p. 209. 1911.

and constituted the second series. The weak point in the system was the mercury valve. The pull increased as the plants became larger, and occasionally this resulted in the pulling-over of the mercury into the cup. In order not to have the pots flooded, the intake was placed in a

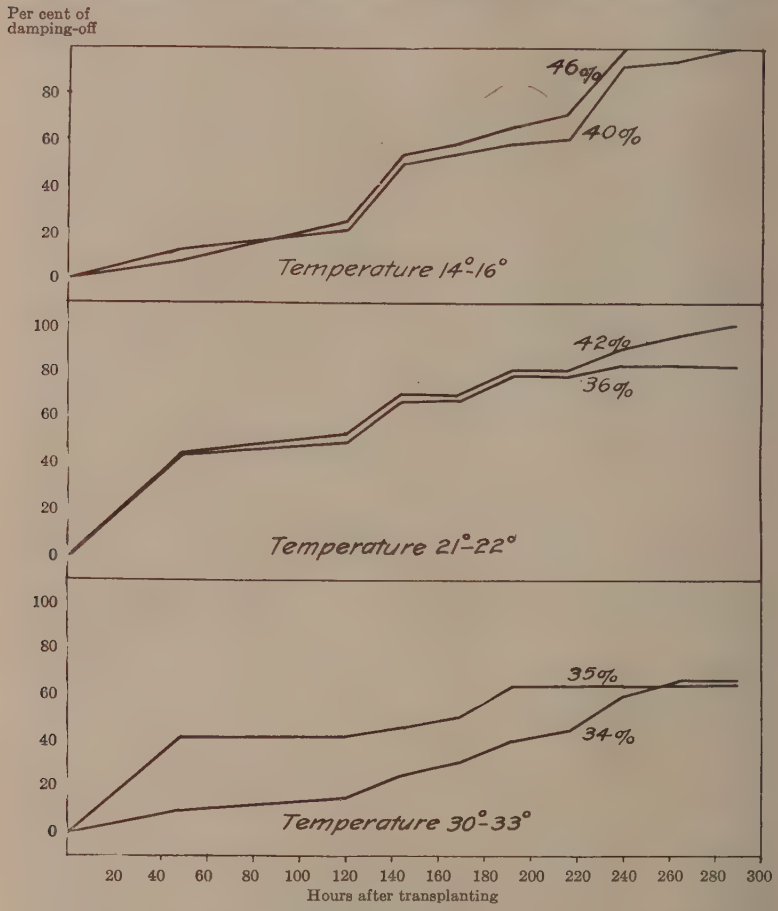

FIGURE 1. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 9, TRIAL I)

Soil moistures are given as percentages

500-cubic-centimeter bottle. This eliminated the danger of flooding, and in addition supplied a means by which the working of the system could be observed. It is obvious that after the water content had been adjusted in each system, each would require about the same amount of water,

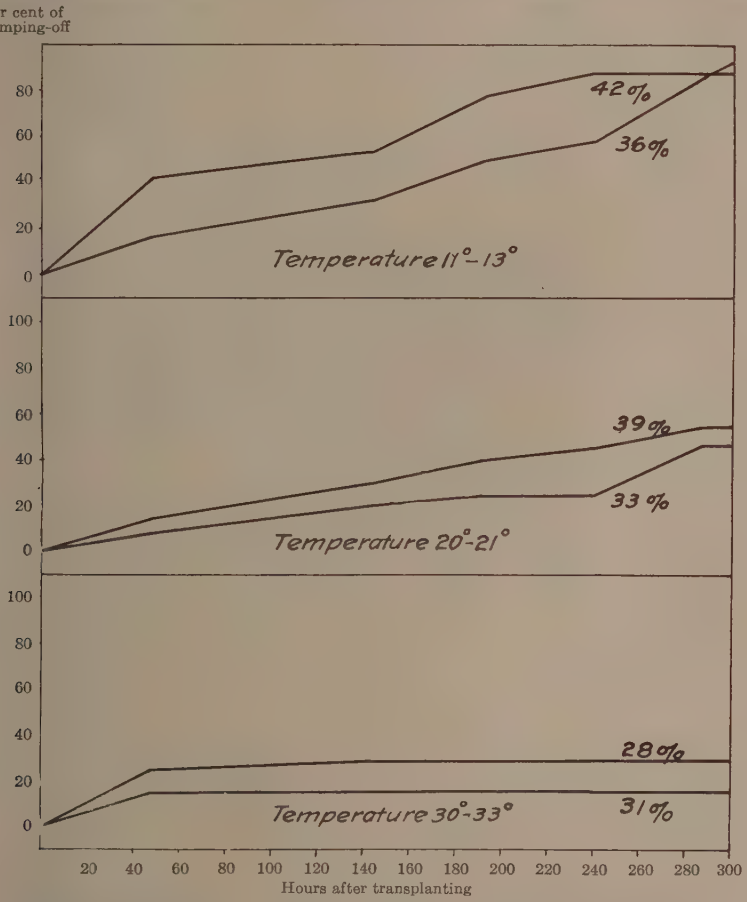

FIGURE 2. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 9, TRIAL II)

Soil moistures are given as percentages

since there was the same amount of soil in the two systems. While results were obtained, this method of moisture control is too cumbersome to be used on a large scale.

The soil was sterilized by autoclaving for from two to three hours under 12 to 18 pounds pressure. The inoculum was mixed into the soil, the system was set up, and the moistures and temperatures were adjusted. Four seedlings were transplanted into each culture vessel. The seedlings were transplanted rather than started in the vessels, because if the seed had been sown directly the seedlings would have been attacked by the fungus before they could push through the soil. Furthermore, several weeks could be gained in this way. This method, however, presented several disadvantages. First, the transplanting was likely to be a definite shock to the plant, and secondly, with the fungus directly in the soil it was impossible to know whether the plant was directly in contact with the inoculum or some distance away from it. Where the difference in the rate as well as the total amount of damping-off was to be compared at the various temperatures and moistures, this represented a large source of error. Also, when the plants were transplanted into the infected soil, a small amount of water had to be given them to insure growth, and this favored the growth of the fungus about the roots. Four jars in each tank were kept as controls. The moisture content was determined after the conclusion of several experiments to insure the uniform operation of the systems for each of the experiments.

During the winter of 1921–22, six trials were made with a total of eighteen temperatures (table 9). In general, the results were similar for all six trials. Damping-off occurred at all of the temperatures tried, but the rate decreased above 30° C. Low temperatures and low moistures were unfavorable for the development of the disease. Determinations made at the end of the trials showed that slightly different moistures resulted at the different temperatures. This was probably due to a more rapid rate of evaporation and transpiration at the higher temperatures. Moisture determinations were made at the conclusion of trials I, II, and VI. In trial VI both irrigation systems became clogged, resulting in a lower moisture content of the soil in both series. For trial IV another set of plants was transplanted into the soil used in the previous experiment without disturbing it any more than was necessary. In this trial, tank 3, which was held at 32° C. in the previous experiments, was lowered to 19.5° C. There was a definite decrease in the rate of damping-off. Whether or not this was due to a decrease in the virulence of the fungus because of the previous high temperatures was not ascertained. For trials V and VI, the upper three inches of the soil was removed from the jars, thoroughly mixed to insure equal distribution of the inoculum, and replaced.

TABLE 9. INFLUENCE OF SOIL TEMPERATURE AND MOISTURE ON WIRE STEM OF CABBAGE CAUSED BY CORTICIUM VAGUM B. & C.

Number of trial	Number of tank	Soil		Percentage of damping-off at indicated hours after transplanting											Condition of plants †			
		Temperature (C.)	Moisture (per cent)*	Hours											I	II	III	IV
				48	120	144	168	192	216	240	264	288	312	384				
				Per cent of damping-off														
I	1	14°–16°	46	8	25	54	58	66	72	100	100	100	100	100	0	5	50	45
		(Mode 15.5°)	40	13	22	50	54	58	60	92	94	100	100	100	0	8	54	38
	2	21°–22°	42	45	53	70	70	81	81	90	95	100	100	100	0	10	20	70
			36	45	50	67	67	79	79	83	83	83	83	83	12	42	17	29
	3	30°–33°	35	42	42	46	50	64	64	64	64	64	64	64	20	40	25	15
		(Mode 30.0°)	34	10	15	25	30	40	45	60	65	65	65	65	25	21	8	46
II	1	11°–13°	42	42	....	54	....	79	....	88	....	88	100	100	0	17	58	25
		(Mode 12.5°).	36	17	....	33	....	50	....	58	....	88	88	88	12	4	75	9
	2	20°–21°	39	15	....	30	....	40	....	45	....	55	55	55	45	5	30	20
			33	8	....	20	....	25	....	25	....	47	47	47	62	13	4	21
	3	30°–33°	31	15	....	15	....	15	....	15	....	15	15	15	90	0	0	10
		(Mode 31°)	28	25	....	29	....	29	....	29	....	29	29	29	75	4	0	21
III	1	10°–13°	42	4	33	33	66	75	83	83	87	87	91	91	9	4	87	0
		(Mode 12°)	36	8	16	29	42	46	54	54	63	63	63	63	17	13	42	28
	2	18°–19°	39	35	65	75	85	90	90	90	90	90	90	90	5	5	55	35
		(Mode 18.5°)	33	30	37	50	50	54	62	62	63	63	63	63	21	21	21	33
	3	31°–34°.	31	20	30	35	40	40	44	44	44	44	44	44	45	15	10	30
		(Mode 31°)	28	25	30	33	37	38	41	42	42	42	42	42	42	33	0	25

* Percentage of maximum retentive power of soil as determined by the Hilgard method.
† I, healthy; II, slightly diseased; III, badly diseased; IV, dead.

TABLE 9 (*concluded*)

Number of trial	Number of tank	Soil: Temperature (C.)	Soil: Moisture (per cent)*	Percentage of damping-off at indicated hours after transplanting: Hours 48	120	144	168	192	216	240	264	288	312	384	Condition of plants †: I	II	III	IV
				Per cent of damping-off														
IV	1	10°–12°	42	54	62	75	75	79	79	87	87	91	92	92	4	8	75	13
		(Mode 11°)	36	8	8	8	16	16	25	37	38	42	46	46	33	13	50	4
	2	24°–25°	39	35	45	60	65	65	70	80	90	90	90	90	10	15	50	25
		(Mode 24.5°)	33	12	25	25	25	29	33	33	33	37	37	37	45	17	25	13
	3	19°–20°	39	15	30	30	30	35	35	35	60	70	70	70	25	30	35	10
		(Mode 19.5°)	33	8	16	20	21	21	21	21	25	25	25	25	58	8	21	13
V	1	12°–13°	42	33	46	50	63	66	79	83	92	92	92	92	0	4	83	13
		(Mode 12.5°)	36	4	12	12	16	21	25	37	37	42	42	42	58	13	21	8
	2	18°–19°	39	30	50	60	60	70	80	80	80	85	85	85	5	25	65	10
		(Mode 18.5°)	33	4	12	29	33	41	50	54	54	58	62	62	50	13	37	0
	3	30°–32°	31	5	5	5	10	10	10	15	25	25	25	25	60	5	30	5
		(Mode 31.5°)	28	4	4	8	12	12	16	16	16	16	16	16	87	0	9	4
VI	1	14°–18°	36	0	0	4	17	17	25	33	38	38	38	38	42	8	46	4
		(Mode 16.5°)	32	0	0	4	17	17	29	37	42	42	42	42	50	12	34	4
	2	22°–24°	30	0	0	4	13	17	25	25	25	29	29	29	60	30	10	0
		(Mode 22.5°)	27	0	0	4	13	17	17	21	21	21	21	21	66	13	8	13
	3	25°–27°	28	0	0	0	4	8	10	12	13	13	13	13	80	10	10	0
		(Mode 25.5°)	26	0	0	0	0	0	0	0	4	4	4	4	83	4	13	0

* Percentage of maximum retentive power of soil as determined by the Hilgard method.
† I, healthy; II, slightly diseased; III, badly diseased; IV, dead.

These experiments were repeated the following year with a reduction in the sources of error encountered in the first year. A complete new system was set up for each trial. First, the gallon jars were replaced by others of the same diameter but not so high (13 by 19 centimeters). These

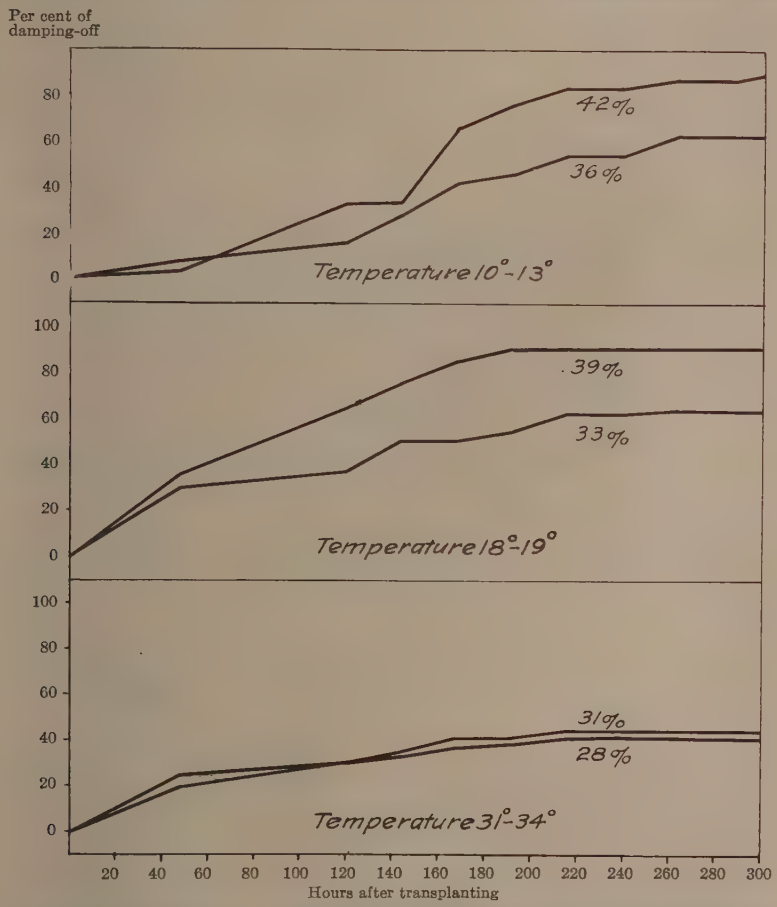

FIGURE 3. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 9, TRIAL III)

Soil moistures are given as percentages

could be elevated from the bottom of the tank by placing them on small inverted flowerpots. Better circulation in the water bath was thus afforded, so that a larger number of culture vessels could be placed in each tank without reducing the uniformity of the temperature. Instead

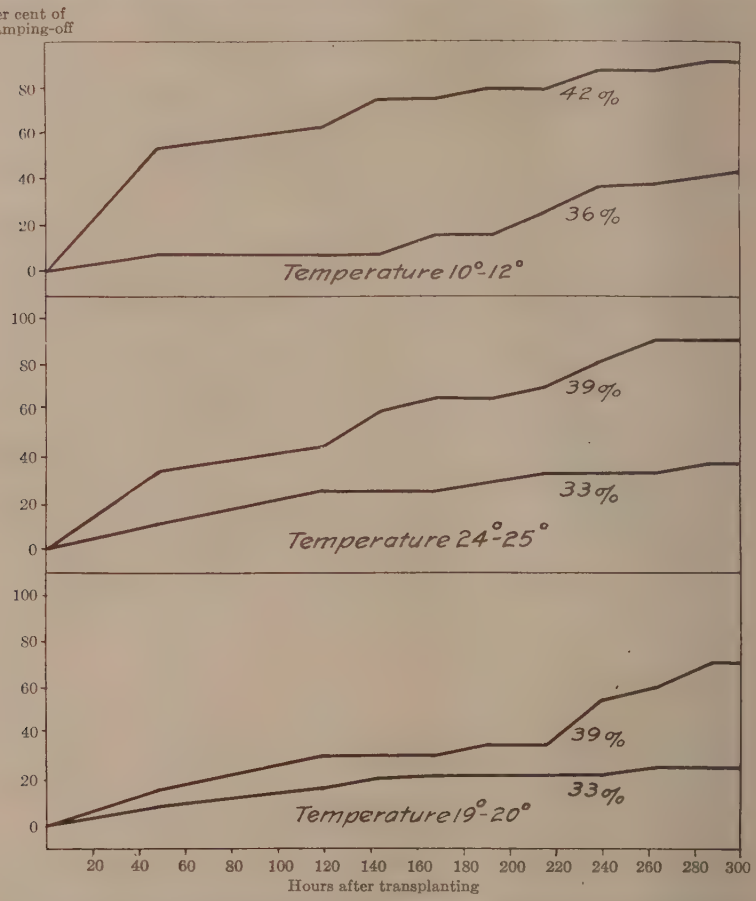

FIGURE 4. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 9, TRIAL IV)

Soil temperatures are given as percentages

of only sixteen culture vessels, twenty-five were now used. The same amount, by weight, of well-screened, sterilized soil was placed in each vessel, and provision was made for watering from the bottom by inserting a glass tube which connected with an inverted 2-inch flowerpot at the

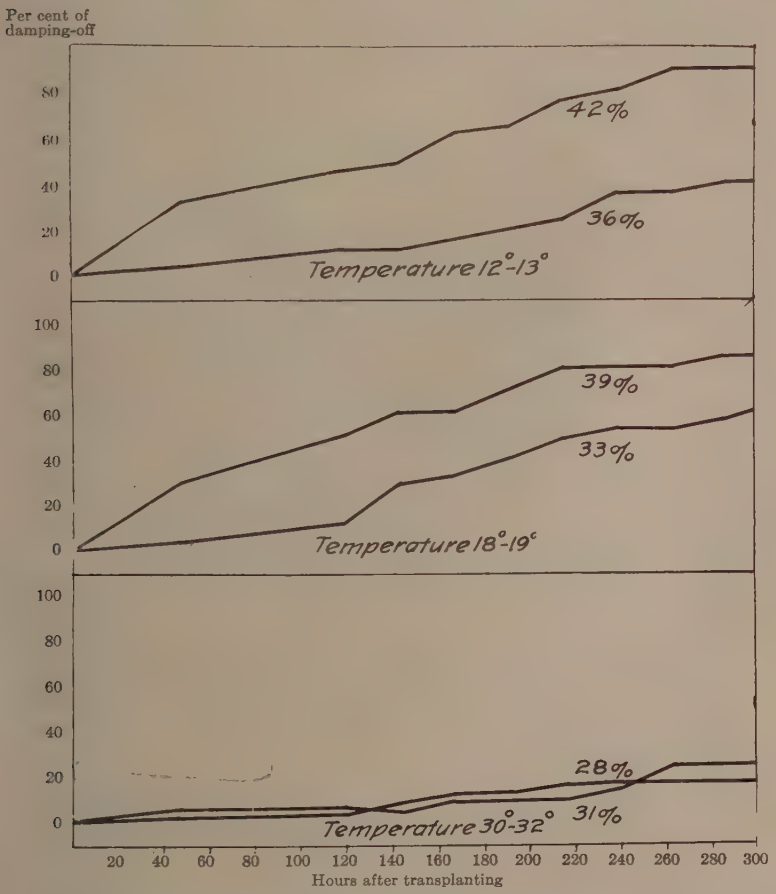

FIGURE 5. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 9, TRIAL V)

Soil moistures are given as percentages

bottom of the soil. The calculated amount of water necessary to produce the desired moisture content of the soil was added through this tube. The maximum retentive power and the actual moisture of the soil were determined previous to the placing of the soil in the jars.

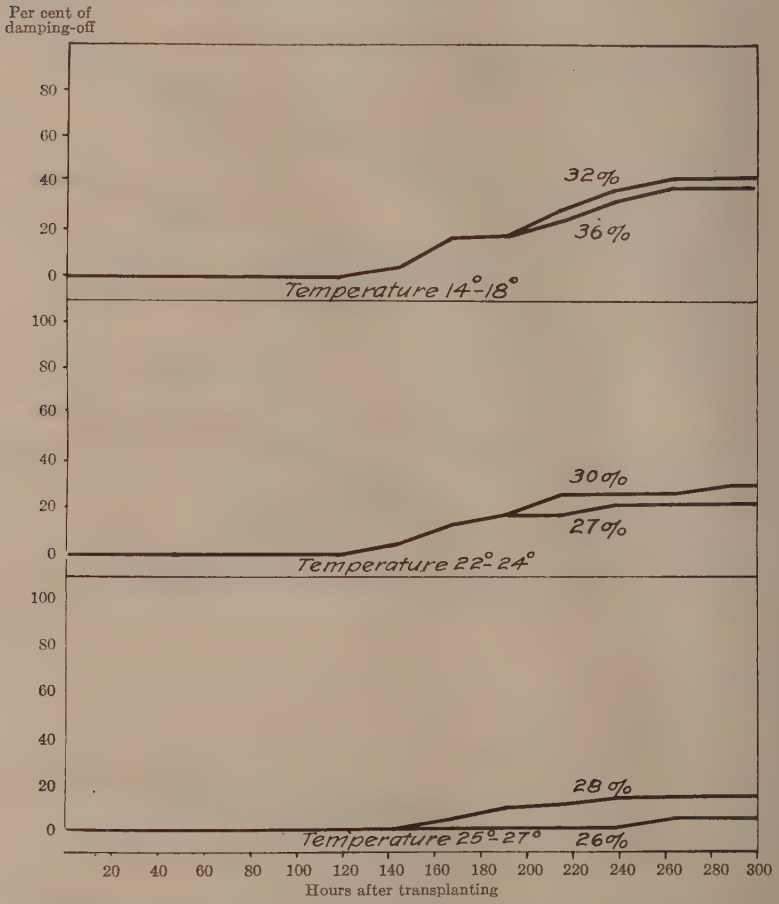

FIGURE 6. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 9, TRIAL VI)

Soil moistures are given as percentages

The tared culture vessels were maintained at constant weight by weighing every day or two, depending on the rate of evaporation and transpiration, and adding the necessary water. Five moisture series were maintained for each tank, with five culture vessels for each series. By this method the moistures in each series in each tank were comparable to their respective series in the other tanks maintained at different temperatures. One jar in each moisture series was kept as a control. Instead of having only four plants for each culture, from twelve to fifteen seedlings were transplanted into each vessel. Thus from forty-eight to sixty plants were growing at each moisture series at each of the three temperatures, not including the culture vessel with the fifteen control plants. The seedlings were allowed to become established (six to eight days) before inoculation. The method of inoculation consisted in placing a grain of wheat, upon which the fungus was growing, about one-quarter inch below the surface of the soil and about that distance from the stem. This permitted the fungus to grow through the soil to the seedling. Several cubic centimeters of water was added to the seedlings at the time of transplanting, to insure their growth. Probably very little of this moisture remained at the base of the seedlings at the time of inoculation. Obviously, since gravity limits the capillary ascent in a progressive ratio,[14] the surface of the soil must have been considerably drier than the bottom layers, and the figures given in the tables are but an approximation for the entire culture vessel, and not for the surface layer, where damping-off actually takes place. It is further to be pointed out that since the Hilgard 1-centimeter-column method is a laboratory procedure and the soil used is not in its normal structural state, figures thus obtained may be from 30 to 130 per cent too high.[15] To determine the amount of water actually required to saturate a column of soil as high as the column used in the culture vessels, a tin pail, of the same size as the jars and with the bottom perforated, was filled with soil to the same height as that in the culture vessels and then set in water, which was allowed to seep through the perforations. After this had drained for a short time, the weight of water taken up was determined. Numerous determinations of this kind indicated that the error introduced by the centimeter-cup method was approximately 70 per cent. The maximum amount of water required to saturate the soil as determined by the Hilgard 1-centimeter-column method was 85 per cent of the dry weight, while but 51 per cent saturated a column of soil as high as that used in the culture vessels. In the tables the moisture contents are expressed as determined by the standard Hilgard method.

The results are tabulated in tables 10 to 15. Inspection of the tables shows that the results of these trials, in the main, agree with those of the preceding year. It is not necessary to discuss each of the experiments in

[14] Hilgard, E. W. Soils, p. 208–209. 1911.
[15] Lyon, T. Lyttleton, and Buckman, Harry O. The nature and properties of soils, p. 162–163. 1922.

detail, except to point out briefly some of the variations in the method. Similar moisture series were maintained in each of the experiments, except in the first of these trials (table 10), in which the highest moisture content was greater than 51 per cent (saturation). The other differences

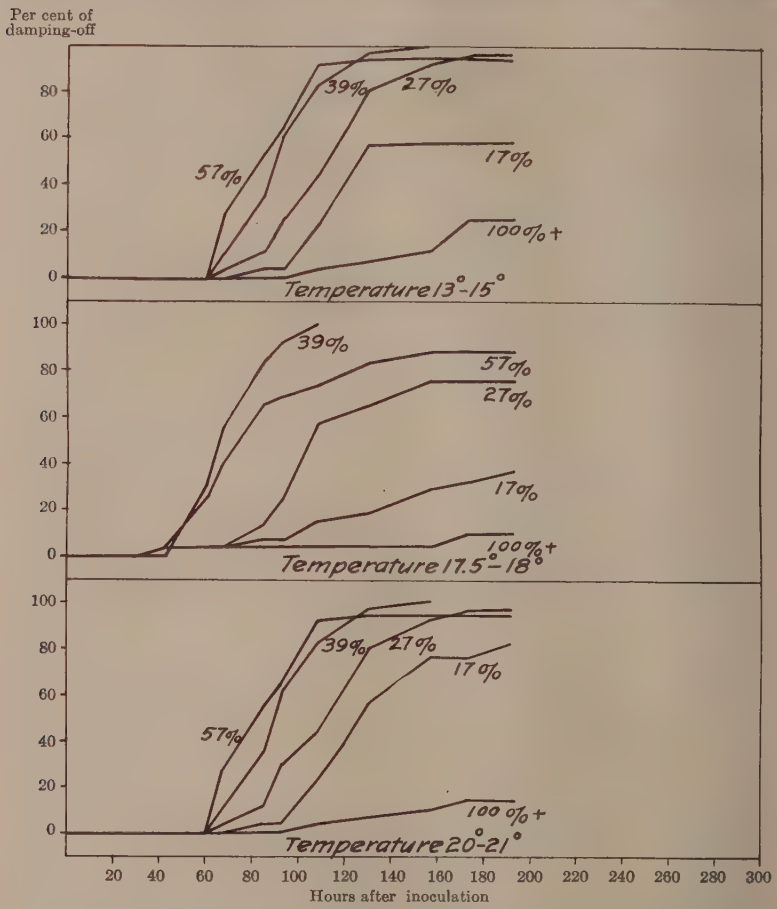

FIGURE 7. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 10, TRIAL VII)

Soil moistures are given as percentages]

in the moisture content were slight and did not alter the results, as will be seen when they are compared with those in the other trials. In all the trials except VII and VIII (tables 10 and 11), a moisture content of 18 per cent was too low to support growth. Apparently the soil in trial

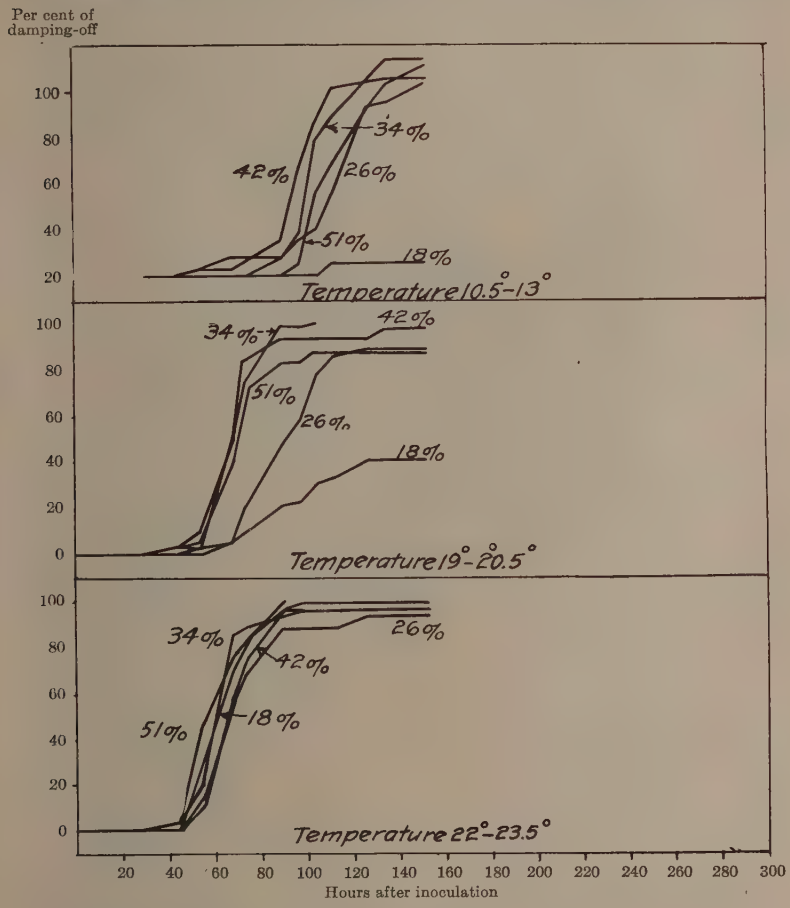

FIGURE 8. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 11, TRIAL VIII)

Soil moistures are given as percentages

VII was of slightly different consistency, as only incipient wilting was observed in the soil with a moisture content of 17 per cent, while in the other trials permanent wilting resulted at this low moisture content. In trial VIII, tank 3 (table 11), the greatest rate of damping-off was observed in the soil where the moisture content was 18 per cent. This was due to the fact that the plants had started to wilt and were given a small amount of water several days previous to inoculation. The total amount of moisture in the culture vessel was not in excess of the required amount, but the immediate area surrounding the seedlings had an excess as compared with the previous experiments. This was a favorable condition for fungus growth. In most of the experiments a soil with a moisture content of 51 per cent caused a delay in the rate of damping-off. This was almost at saturation and a detrimental effect on the host was also noted. In trial X (table 13) an error was made in the original calculation, and consequently two moistures were obtained where permanent wilting occurred. The redeterminations at the end of the experiment indicated just what these moistures were. In trials X and XI (tables 13 and 14), the low temperature was maintained by packing snow in one end of the tank. The heater was also in operation to prevent any undercooling. The uniformity of temperatures maintained is indicated in figure 9.

In all the preceding experiments, none of the check plants developed the disease.

Good growth of the host was observed at all temperatures between 15° and 30° C. Temperatures below 15° slightly decreased the rate of growth, but it was only at the lowest temperature (5.5° C.) that the plants made very little growth. Even at that temperature the plants were in a very thrifty condition at the end of the experiment. Above 30° C. the growth was rapid, but the plants were not so intensely green in color as at the lower temperatures, and they showed clearly the effects of the abnormal environmental conditions.

The following conclusions are to be drawn from these temperature-moisture experiments:

1. A temperature of approximately 7° or 8° C. is the minimum for damping-off of cabbage seedlings caused by *Corticium vagum*, as a small number of diseased plants were obtained at 10° C. and none at approximately 5.5° C. (tables 13 and 14).

2. A temperature of 31° to 32° C. is the maximum for the destructive action of the fungus (tables 9, 13, and 15).

3. There is no sharply defined optimum, but a rapid rate of damping-off may occur at any temperature from 15° C. to 30° C. There is a decrease from these temperatures until the respective limits are reached (tables 9 to 15).

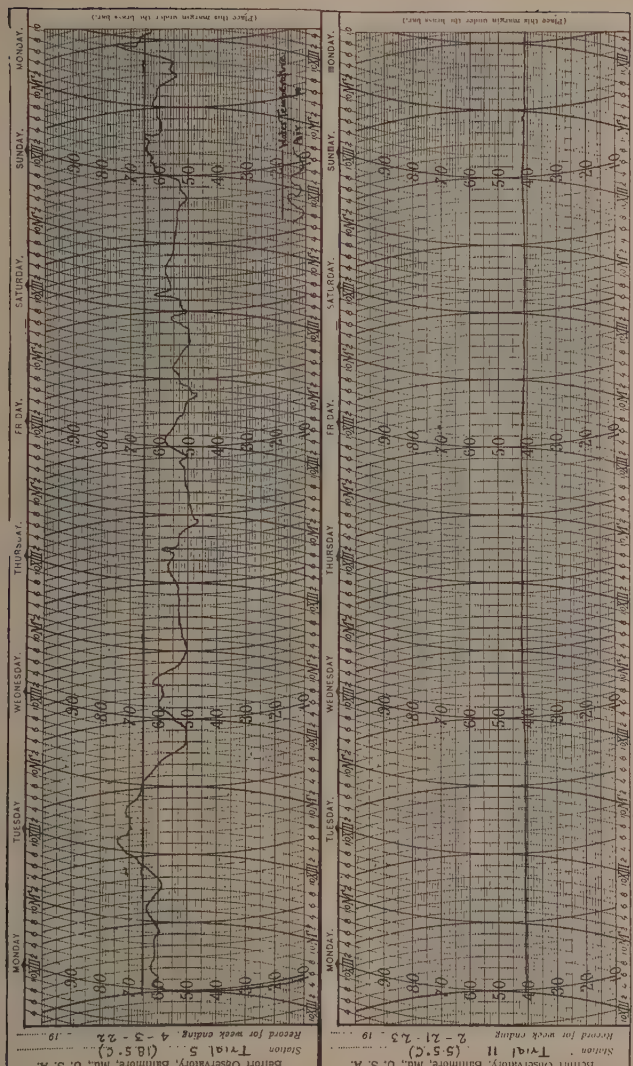

FIGURE 9. THERMOGRAPH RECORDS ILLUSTRATING THE UNIFORMITY OF BOTH LOWER AND HIGHER TEMPERATURES MAINTAINED IN TANKS DURING INVESTIGATIONS OF WIRE STEM OF CABBAGE

TABLE 10. INFLUENCE OF SOIL TEMPERATURE AND MOISTURE ON WIRE STEM OF CABBAGE CAUSED BY CORTICIUM VAGUM B. & C.

Number of trial	Number of tank	Soil: Temperature (C.)	Soil: Moisture (per cent)*	Percentage of damping-off at indicated hours after inoculation: Hours: 30	42	60	67	85	93	108	130	157	173	192	Condition of plants†: I	II	III	IV
				Per cent of damping-off														
VII	1	13°–15° (Mode 14.8°)	17	0	0	0	0	4	4	23	57	58	58	58	42	0	58	0
			27	0	0	0	4	11	26	44	81	93	96	96	4	8	81	7
			39	0	0	0	11	36	61	83	97	100	100	100	0	0	60	40
			57	0	0	0	27	54	65	92	95	95	95	95	5	3	69	23
			100+	0	0	0	0	0	0	4	7	11	25	25	75	0	0	25
	2	17.5°–18° (Mode 17.5°)	17	0	4	4	4	7	7	15	19	30	33	37	63	16	14	7
			27	0	4	4	4	14	25	58	65	76	76	76	24	8	57	11
			39	0	0	30	56	85	93	100	100	100	100	100	0	0	68	32
			57	0	0	27	38	65	69	73	84	88	88	88	12	11	63	14
			100+	0	4	4	4	4	4	4	4	4	10	10	90	6	0	4
	3	20°–21° (Mode 20.0°)	17	0	0	0	0	4	4	23	57	76	76	82	18	0	62	20
			27	0	0	0	4	11	30	44	81	93	96	96	4	0	18	78
			39	0	0	0	11	36	61	83	97	100	100	100	0	0	30	70
			57	0	0	0	27	54	65	92	95	95	95	95	5	0	70	25
			100+	0	0	0	0	0	0	4	7	10	14	14	86	14	0	0

* Percentage of maximum retentive power of soil as determined by the Hilgard method.
† I, healthy; II, slightly diseased; III, badly diseased; IV, dead.

TABLE 11. INFLUENCE OF SOIL TEMPERATURE AND MOISTURE ON WIRE STEM OF CABBAGE CAUSED BY CORTICIUM VAGUM B. & C.

Number of trial	Number of tank	Soil		Percentage of damping-off at indicated hours after inoculation												Condition of plants†			
		Temperature (C.)	Moisture (per cent)*	Hours															
				30	45	54	68	74	90	98	105	112	127	136	152	I	II	III	IV
				Per cent of damping-off															
VIII	1	10.5°–13° (Mode 12°)	18	0	0	0	0	0	0	0	0	5	5	5	5	95	5	0	0
			26	0	0	0	0	0	8	15	20	35	73	75	83	0	15	83	2
			34	0	0	3	8	8	8	18	58	68	83	93	93	8	2	85	5
			42	0	0	3	3	5	15	45	65	80	83	85	85	10	10	80	0
			51	0	0	0	0	0	0	5	35	48	72	83	90	3	5	92	0
	2	19°–20.5° (Mode 20°)	18	0	3	3	5	10	20	23	30	33	40	40	40	45	10	35	10
			26	0	0	0	5	20	48	58	78	85	88	88	88	8	5	37	50
			34	0	3	8	53	75	98	98	100	100	100	100	100	0	0	37	63
			42	0	0	3	50	83	93	93	93	93	93	97	97	3	3	47	47
			51	0	3	5	40	73	83	83	87	87	87	87	87	7	16	70	7
	3	22°–23.5° (Mode 23°)	18	0	0	28	70	83	100	100	100	100	100	100	100	0	0	3	97
			26	0	0	15	55	68	88	88	88	88	93	93	93	7	3	25	65
			34	0	3	20	85	88	93	95	95	95	95	95	95	3	5	33	59
			42	0	0	13	58	75	95	98	98	98	98	98	98	2	3	55	40
			51	0	3	45	75	83	95	95	95	95	95	95	95	5	7	73	15

* Percentage of maximum retentive power of soil as determined by the Hilgard method.
† I, healthy; II, slightly diseased; III, badly diseased; IV, dead.

TABLE 12. INFLUENCE OF SOIL TEMPERATURE AND MOISTURE ON WIRE STEM OF CABBAGE CAUSED BY CORTICIUM VAGUM B. & C.

Number of trial	Number of tank	Soil: Temperature (C.)	Soil: Moisture (per cent)*	Percentage of damping-off at indicated hours after inoculation: Hours 30	48	54	68	74	90	98	105	112	127	136	152	Condition of plants† I	II	III	IV
				Per cent of damping-off															
IX	1	10°–13° (Mode 12°)	18	Permanent wilting															
			26	0	0	0	0	0	0	0	2	7	7	14	14	32	20	48	0
			34	0	0	0	0	0	0	8	20	41	54	76	76	0	5	95	0
			42	0	0	0	0	0	0	5	15	38	53	83	83	0	0	100	0
			51	0	0	0	0	0	0	3	15	33	53	83	83	0	0	100	0
	2	18°–19° (Mode 18°)	18	Permanent wilting															
			26	0	0	0	0	3	13	18	26	51	77	85	85	0	5	87	8
			34	0	0	0	0	41	51	88	95	100	100	100	100	0	0	56	44
			42	0	0	0	0	47	77	97	100	100	100	100	100	0	0	83	17
			51	0	0	5	5	40	58	83	88	100	100	100	100	0	0	52	48
	3	28°–30° (Mode 28°)	18	Permanent wilting															
			26	0	0	0	0	3	13	20	30	35	40	45	45	42	25	18	15
			34	0	0	12	12	48	69	86	88	90	90	93	93	5	0	15	80
			42	0	0	23	23	75	90	95	98	98	98	98	98	0	5	8	87
			51	0	0	62	26	71	82	93	95	95	95	95	95	0	5	15	80

* Percentage of maximum retentive power of soil as determined by the Hilgard method.
† I, healthy; II, slightly diseased; III, badly diseased; IV, dead.

TABLE 13. INFLUENCE OF SOIL TEMPERATURE AND MOISTURE ON WIRE STEM OF CABBAGE CAUSED BY CORTICIUM VAGUM B. & C.

Number of trial	Number of tank	Soil		Percentage of damping-off at indicated hours after inoculation														Condition of plants†			
		Temperature (C.)	Moisture (per cent)*	Hours																	
				30	48	72	80	96	104	120	128	144	152	168	172	192	216	240	I	II	III	IV
				Per cent of damping-off																	
X	1	9°–11° (Mode 10°)	12	..	..	..	..	..	....	....	Permanent wilting				....	....	....	....	....	....	....	....
			18	..	..	..	..	..	....	....	Permanent wilting				....	....	....	....	....	....	....	....
			26	0	0	0	0	0	0	0	0	3	3	3	3	6	9	18	38	32	30	0
			34	0	0	0	0	0	0	0	0	6	9	9	18	42	45	58	21	9	64	6
			42	0	0	0	0	0	0	0	0	0	3	3	23	45	52	55	21	9	70	0
	2	13°–15° (Mode 14°)	12	..	..	..	..	..	....	....	Permanent wilting				....	....	....	....	....	....	....	....
			18	..	..	..	..	..	....	....	Permanent wilting				....	....	....	....	....	....	....	....
			26	0	0	0	0	0	0	0	0	0	0	5	5	11	14	14	83	7	10	0
			34	0	0	0	0	0	5	27	44	54	59	64	68	76	78	80	15	0	77	8
			42	0	0	0	0	7	19	65	79	93	95	98	100	100	100	100	0	0	95	5
	3	29°–32° (Mode 31°)	12	..	..	..	..	..	....	....	Permanent wilting				....	....	....	....	....	....	....	....
			18	..	..	..	..	..	....	....	Permanent wilting				....	....	....	....	....	....	....	....
			26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	98	2	0	0
			34	0	0	0	0	3	3	3	3	3	5	5	5	5	5	5	95	3	2	0
			42	0	3	10	12	24	27	29	29	29	29	29	29	29	29	38	60	25	2	13

* Percentage of maximum retentive power of soil as determined by the Hilgard method.
† I, healthy; II, slightly diseased; III, badly diseased; IV, dead.

TABLE 14. INFLUENCE OF SOIL TEMPERATURE AND MOISTURE ON WIRE STEM OF CABBAGE CAUSED BY CORTICIUM VAGUM B. & C.

Number of trial	Number of tank	Soil: Temperature (C.)	Soil: Moisture (per cent)*	Percentage of damping-off at indicated hours after inoculation: Hours 30	48	64	72	90	96	115	123	138	146	160	190	240	264	Condition of plants† I	II	III	IV
				Per cent of damping-off																	
XI	1	5.5°–7° (Mode 5.5°)	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0
			26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0
			34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0
			42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0
			51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100	0	0	0
	2	24.5°–26° (Mode 25°)	18	.....	.....	.....	.....	.....	.....	Permanent wilting	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
			26	0	0	0	2	2	4	13	13	18	24	30	30	33	35	61	30	9	0
			34	0	9	33	48	61	66	72	74	76	78	78	80	80	80	15	26	49	10
			42	0	4	42	50	81	83	85	85	85	88	88	88	88	95	13	20	59	8
			51	0	2	14	17	26	26	28	28	28	28	28	28	33	33	73	16	9	2

* Percentage of maximum retentive power of soil as determined by the Hilgard method.
† I, healthy; II, slightly diseased; III, badly diseased; IV, dead.

TABLE 15. INFLUENCE OF SOIL TEMPERATURE AND MOISTURE ON WIRE STEM OF CABBAGE CAUSED BY CORTICIUM VAGUM B. & C.

Number of trial	Number of tank	Soil: Temperature (C.)	Soil: Moisture (per cent)*	Percentage of damping-off at indicated hours after inoculation: Hours	30	48	72	80	96	104	120	128	144	152	168	172	192	216	240	Condition of plants†	I	II	III	IV
				Per cent of damping-off																				
XII	1	24°–26° (Mode 25.5°)	18	Permanent wilting																				
			26		0	0	0	3	3	3	3	3	3	3	4	7	7	7	7		93	7	0	0
			34		0	0	2	6	6	6	6	6	6	6	8	14	14	14	14		92	0	8	0
			42		0	0	9	14	21	32	36	43	45	46	50	50	50	50	50		25	25	46	4
			51		0	0	12	26	33	40	43	46	50	55	60	60	60	60	60		5	48	47	0
	2	32°–34° (Mode 32.5°)	18	Permanent wilting																				
			26		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		100	0	0	0
			34		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		100	0	0	0
			42		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		100	0	0	0
			51		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		100	0	0	0

* Percentage of maximum retentive power of soil as determined by the Hilgard method.
† I, healthy; II, slightly diseased; III, badly diseased; IV, dead.

4. Temperature conditions are a greater factor than the total number of diseased plants, in affecting the rate of development of the disease, since frequently, at the ordinary temperatures, it is but a matter of time until a large proportion of the plants are diseased (tables 9 to 15).

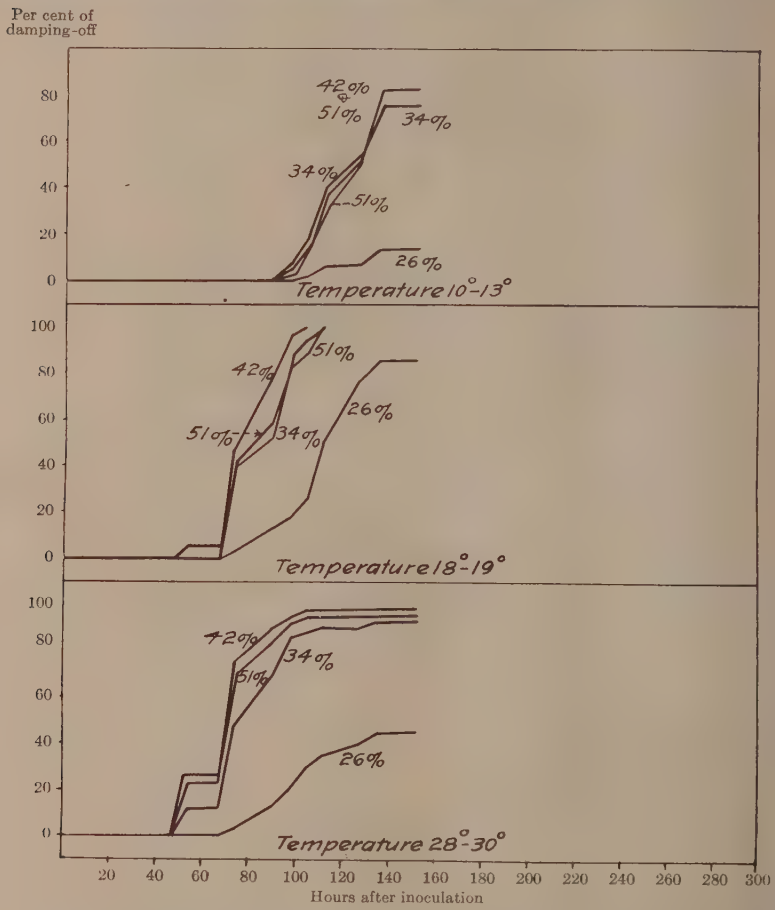

FIGURE 10. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 12, TRIAL IX)

Soil moistures are given as percentages

5. Any soil moisture favorable for the growth of the host is favorable for the growth of the fungus, as damping-off resulted at the lowest moistures in which the plants would grow. In a few cases, incipient wilting was observed in the checks of the lower moistures, where the percentage of

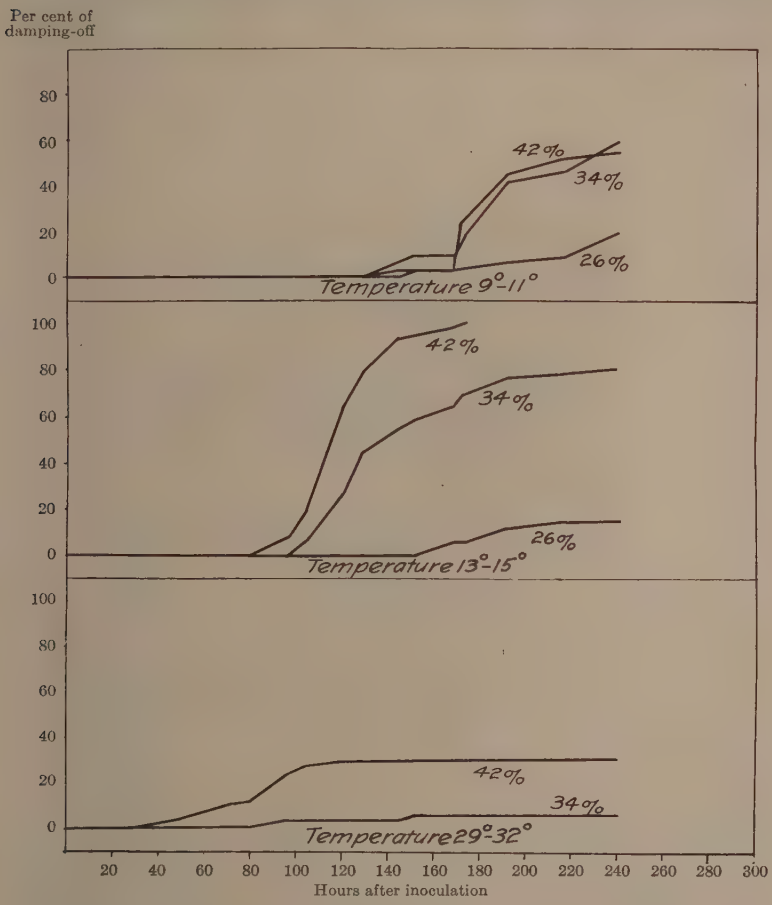

FIGURE 11. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 13, TRIAL X)

Soil moistures are given as percentages

damping-off was high. Excess moistures injurious to the parasite were at the same time injurious to the host, but this occurred only in practically saturated soils (tables 10 to 15).

6. A combination of low temperatures and low moistures greatly delays the rate of damping-off. In some instances the total percentage of

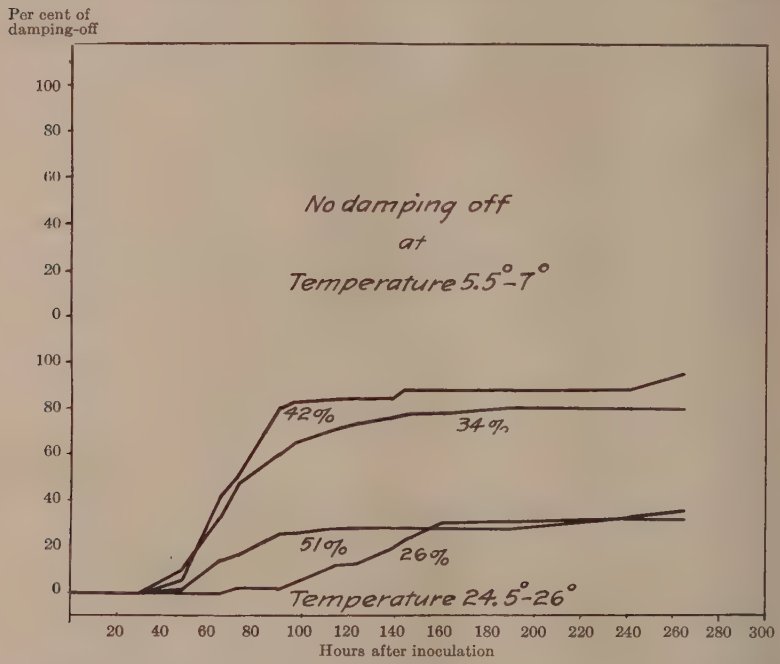

FIGURE 12. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 14, TRIAL XI)

Soil moistures are given as percentages

diseased plants is also decreased, but not materially so in all these instances (trials VI to XII, tables 9 to 15).

It was hardly to be supposed that plants growing at a very low temperature would in any way acquire a resistance to further attack of the parasite. The fact that they would not was definitely indicated when those plants kept at 5.5° C. (table 14) for 264 hours after inoculation practically all damped-off within 48 hours after being subjected to a temperature of 25° C. Only half of the plants were placed at this temperature at first,

and the remainder were kept as controls; but as soon as the first lot had succumbed with such rapidity, the others were likewise placed at that temperature with similar results. This experiment was later duplicated by growing one hundred and eighty plants (twelve culture vessels) at a temperature of 12° C. for three weeks, and another equal number of seedlings

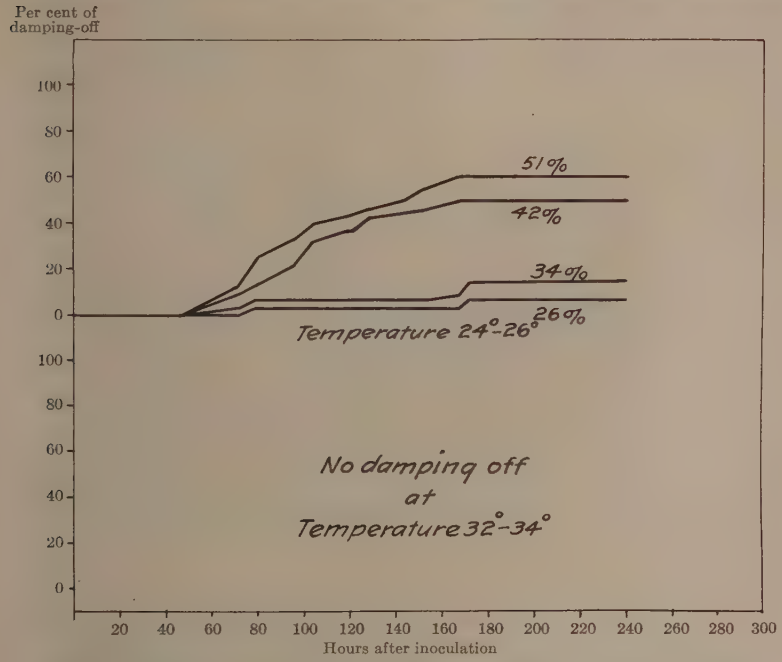

FIGURE 13. INFLUENCE OF DIFFERENT SOIL TEMPERATURES AND SOIL MOISTURES ON RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS CAUSED BY CORTICIUM VAGUM (TABLE 15, TRIAL XII)

Soil moistures are given as percentages

at 30° C. for the same length of time, and finally placing them in the same tank at 20° C. They were immediately inoculated by placing the inoculum in direct contact with the seedling. The rate as well as the total percentage of damping-off was practically the same in both sets of seedlings. The moistures were the same in all the culture vessels.

One of the interesting observations in the experiments is that of the definite lag in the rate of damping-off in those trials (VI, XI, and XII, tables 9, 14, and 15) which were performed in April, when the air tempera-

tures were comparatively higher than when the other trials were made. Here is shown the intimate relationship between the air and soil temperatures. Careful air-temperature records were kept at all times. Such records are given in table 16. These temperatures were not so high as the maximum for the growth of the fungus, but were nevertheless much

TABLE 16. THE DIFFERENT MAXIMUM, MINIMUM, AND AVERAGE AIR TEMPERATURES UNDER WHICH TRIALS VI, XI, AND XII WERE PERFORMED

Number of trial	Temperatures (centigrade)		
	Minimum	Maximum	Average
VI	5°–17°	15°–29°	11°–20°
XI	9°–16°	17°–30°	11°–23°
XII	13°–20°	22°–33°	16°–27°

beyond the optimum temperature. They were a deciding factor both directly in the growth of the fungus, and in drying out the surface layer of the soil, thus delaying growth. There is no need of giving further data, but similar figures could be given where a similar increase in the air temperature the previous year was accompanied by a corresponding decrease in the rate of damping-off. The supposition that such decreases were due to the inoculum can hardly hold, as the inoculum for all of these later trials was the same as that used previously and had been prepared a longer time before inoculation than in the earlier experiments. This might have insured even a more thorough infection of the wheat grains with the mycelium, and more sclerotial formation, if that were possible.

Bottom as compared with top watering.

The foregoing experiments emphasize the importance of the water content of the surface soil as a factor in determining the health of plants growing in infected soil. This is especially illustrated in trial VIII (table 11), where the plants even in a dry soil damped-off forthwith, because the moisture content in the immediate vicinity of the seedlings had been increased several days previous to inoculation. This is in accordance with the recommendations of Jones (1908) and of Johnson (1914), who suggest keeping the surface soil dry in order to delay damping-off. To obtain some definite data, three culture vessels with a total of thirty-three seedlings, watered by sprinkling the surface, were inoculated, and were compared with two vessels containing twenty-one plants which were given the same amount of water added to the bottom of the soil. All other conditions were similar. There was considerably less damping-off in the latter case, as well as a decrease in the rate (table 17). This experiment was repeated with sixty plants (four culture vessels) for each of

TABLE 17. RESULTS OF PRELIMINARY EXPERIMENT SHOWING DIFFERENT RATE OF DAMPING-OFF IN WET AND DRY SURFACE SOILS

Days after inoculation	Rate of damping-off (per cent)	
	Surface watered	Bottom watered
3	9	0
4	21	0
5	73	14
6	88	24
7	97	48
9	100	52
10	100	62

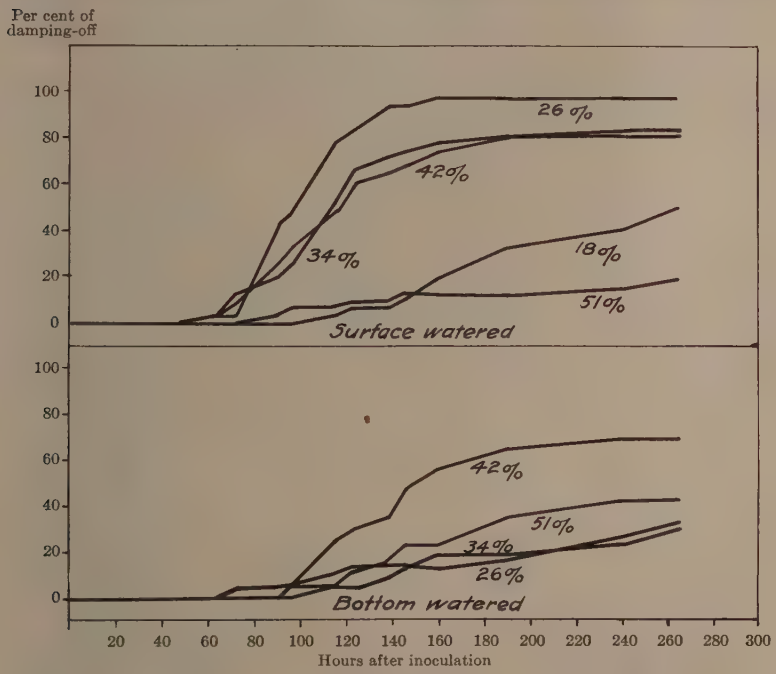

FIGURE 14. DIFFERENCE IN RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS IN SOIL THAT IS SURFACE-WATERED, AND SOIL THAT IS BOTTOM-WATERED (TABLE 18, TRIAL XIII)

Soil moistures are given as percentages

TABLE 18. INFLUENCE OF SOIL TEMPERATURE AND MOISTURE ON WIRE STEM OF CABBAGE CAUSED BY CORTICIUM VAGUM B. & C.

Number of trial	Number of tank	Soil: Temperature (C.)	Soil: Moisture (per cent)*	Percentage of damping-off at indicated hours after inoculation: Hours 30	48	64	72	90	96	115	123	138	146	160	190	240	264	Condition of plants† I	II	III	IV
				Per cent of damping-off																	
				Surface watered																	
XIII	3	12°–16°	18	0	0	0	0	0	0	3	7	7	10	20	33	40	50	3	97	0	0
			26	0	0	3	3	44	48	79	85	94	94	97	97	97	97	3	0	72	25
			34	0	0	3	11	19	25	53	67	72	75	78	81	81	81	6	17	77	0
			42	0	0	3	9	26	34	48	60	65	69	74	80	83	83	12	0	88	0
			51	0	0	0	0	3	6	6	8	8	11	11	11	14	19	85	5	5	5
				Bottom watered																	
			18							Permanent wilting								96	4	0	0
			26	0	0	0	4	4	4	4	4	8	13	13	16	25	33	42	16	42	0
			34	0	0	0	0	0	5	10	14	14	14	19	19	24	29	55	15	30	0
			42	0	0	0	0	0	4	26	30	35	48	57	65	69	69	26	17	57	0
			51	0	0	0	0	0	0	4	12	15	23	23	35	42	42	58	23	8	11

* Percentage of maximum retentive power of soil as determined by the Hilgard method.
† I, healthy; II, slightly diseased; III, badly diseased; IV, dead.

five moistures, not counting the control plants. Results similar to those in the previous experiment were obtained. Permanent wilting resulted in bottom-watered soil with a moisture content of 18 per cent. Incipient wilting only resulted at that moisture when the water was added to the surface of the soil. The rate as well as the total number of diseased plants was greatly increased by surface watering (table 18 and figure 14). This is a bit of experimental evidence, little of which is found in literature in support of the recommendations mentioned above. The fact that little such evidence is found is probably because it concerns a fact apparently too obvious to require experimental proof.

Effect of surface layer of sand

The question as to the most practicable method of maintaining such a dry surface still remains. Probably a current recommendation is a covering of sand. Johnson (1914) and Sherbakoff (1917 b), however, give rather conflicting opinions. Johnson thinks that such a practice is of doubtful value, while Sherbakoff states:

> It is often advantageous to have on the surface of the seed bed a half-inch layer of pure, coarse sand. Damping off fungi grow on the surface or in upper layers of the soil and thrive best when the soil is well supplied with organic matter. This layer of pure sand will hinder the growth of the fungi.

To obtain some data on this phase of the subject, the following experiments were performed:

1. Naturally infected soil was thoroughly mixed and placed in flats. Seed was sown in the ordinary way and covered very lightly with soil, and a $\frac{1}{4}$-inch layer of clean, coarse sand was placed over the surface. Only 50 per cent of the seedlings pushed through the surface. On investigation it was found that all the seed germinated, but half of the seedlings were destroyed before they reached the surface. All the plants which actually started to grow damped-off later. Apparently the sand, instead of permitting rapid surface evaporation, prevented it and formed an ideal environment at the soil-and-sand juncture for damping-off.

2. Another flat was sown to seed where the soil consisted of a mixture of 50 per cent of infected soil and 50 per cent of sand. Although practically 100 per cent germination occurred, only 8 per cent of the seedlings reached the surface of the soil. All of these damped-off later.

3. Seed was sown on top of the infected soil in another flat, and covered with sand only. Here all germinated and grew, but later damped-off.

4. As a control for the above-mentioned experiments, seed was sown in infected soil containing no sand. Twenty-eight per cent of the seedlings emerged, and all damped-off. All the seed in a flat of sterilized soil germinated and remained disease-free.

5. At a later date, seed was again sown in several flats of infected soil and the surface was covered with coarse sand. These flats were all given

the same amount of water. Again the germination was 100 per cent, but only 35 per cent of the plants came through the soil, the remaining 65 per cent exhibiting definite, blackened, dead sprouts that had emerged from the seeds. Of the 35 per cent, all developed wire stem. All the seeds not covered with sand reached the surface of the soil, and only one-third of these damped-off or developed wire stem.

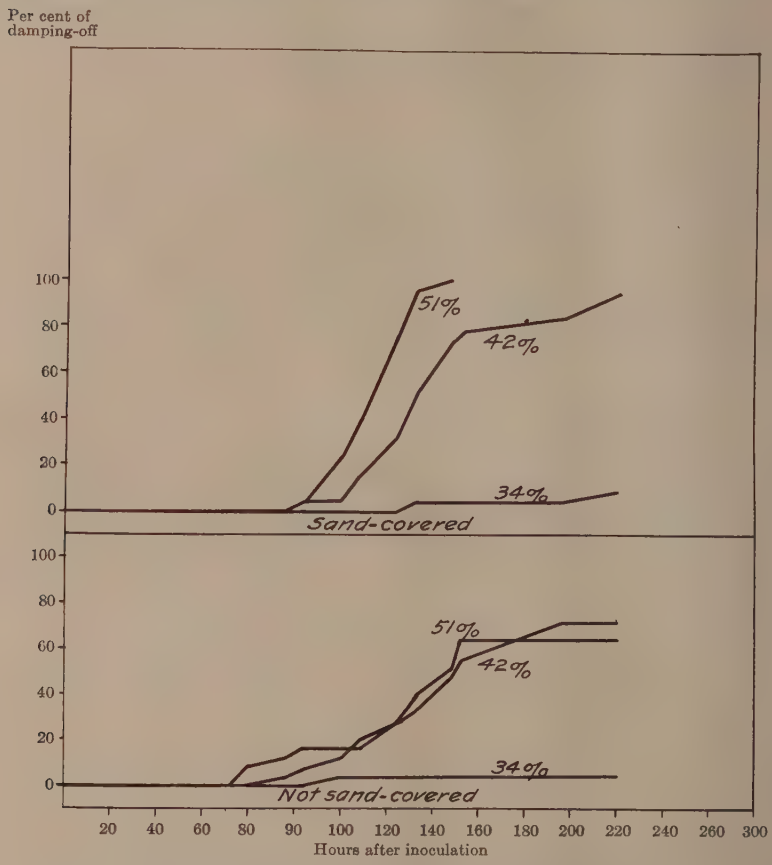

FIGURE 15. INCREASE IN RATE OF DAMPING-OFF OF CABBAGE SEEDLINGS IN SOIL COVERED WITH A LAYER OF FINE QUARTZ SAND (TABLE 19)

Soil moistures are given as percentages

These experiments indicate that sand may even be detrimental. Whether or not this is actually so in every case cannot be stated positively until further experimental work has been done.

Another experiment was performed to determine the influence of a surface layer of sand on the evaporation of water from the soil. Fine quartz sand was used, instead of the coarse sand employed in the previous experiments. Four culture vessels were used in each of five moistures. All the cultures were watered through glass tubes extending to the bottom of the vessels. About fifteen seedlings were transplanted into each jar as before, and were allowed to grow for a week. Inoculations were then made, and immediately the surface of two of the culture vessels in each moisture series was covered with a layer of sand about one-quarter inch deep. The moisture content was kept constant by weighing every other day and adding the required amount of water. During the entire experiment the sand-covered vessels lost only about half as much water as did those that were not covered. It was thus to be expected that the covered vessels were the more ideal for the development of the disease, and later observations demonstrated this to be the case (table 19 and figure 15).

TABLE 19. INFLUENCE OF A LAYER OF QUARTZ SAND ON THE SURFACE OF THE SOIL, ON DAMPING-OFF CAUSED BY CORTICIUM VAGUM B. & C.

Number of tank	Soil moisture* (per cent)	Percentage of damping-off at indicated hours after inoculation. Soil temperature, 16–20° C.											
		Hours											
		72	80	96	104	120	128	144	152	168	172	216	240
		Per cent of damping-off											
		Sand-covered											
3	18	Permanent wilting											
	26	0	0	0	0	0	0	0	0	0	0	0	0
	34	0	0	0	0	0	0	0	4	4	4	4	8
	42	0	0	0	4	4	16	32	52	74	78	84	96
	51	0	0	0	4	24	40	76	96	100	100	100	100
		Not sand-covered											
	18	Permanent wilting											
	26	0	0	0	0	0	0	0	0	0	0	0	0
	34	0	0	0	0	4	4	4	4	4	4	4	4
	42	0	8	12	16	16	16	28	32	48	56	72	72
	51	0	0	4	8	12	20	28	40	52	64	64	64

* Percentage of maximum retentive power of soil as determined by the Hilgard method.

CONTROL

Although the subject of the control of wire stem was not investigated thoroughly, certain phases of the experiments described above are important in indicating lines of attack. The disease cannot be controlled by changes in the environmental conditions. A low temperature and a dry surface soil may reduce the disease or delay it, but not sufficiently to warrant such a procedure as a control measure. The fungus must be killed before the seed or the seedlings are placed in the infected soil, if freedom from the disease is to be insured. The method of eradication is obviously soil sterilization. This can best be done by thorough steaming of the soil or by drenching it with formaldehyde. The latter method was used as recommended by Johnson, with good results (Johnson, 1914, and Sherbakoff, 1917, a and b). Calcium hypochlorite, up to sufficient quantities to kill the host plant, had no value in controlling the disease when used as a soil disinfectant. The Cheshunt mixture (Bewley, 1921–22) was tried at the recommended strength on several occasions. At every trial there was a delay of several days in the appearance of the disease, but later no difference was observed in the percentage of diseased plants growing in treated and in untreated soil.

SUMMARY

Wire stem of cabbage is caused by a strain of *Corticium vagum* B. & C. which is physiologically distinct from the strains causing lesions on potato stems. Of the strains from potatoes with which the writer worked, none were found to be pathogenic to cabbage, and likewise the strain from cabbage seedlings did not produce lesions on potato stems.

The minimum and maximum temperatures for the growth of the fungus in pure culture are approximately 9° and 31° C. The optimum is not sharply defined, but it lies between 22° and 26° C.

The fungus exhibits a wide pH range for growth, the minimum being approximately 2.0 and the maximum above 10.4. The optimum is about 6.2.

Practically any combination of soil temperatures and moistures favorable for the growth of the host is favorable for the growth of the fungus and for the development of wire stem. Consequently, no changes in the environmental conditions will control the disease.

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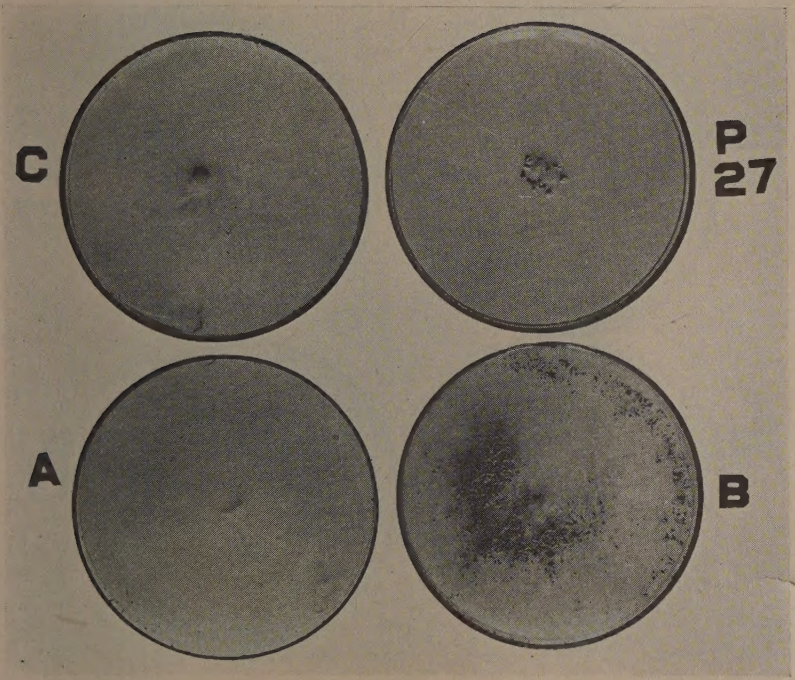
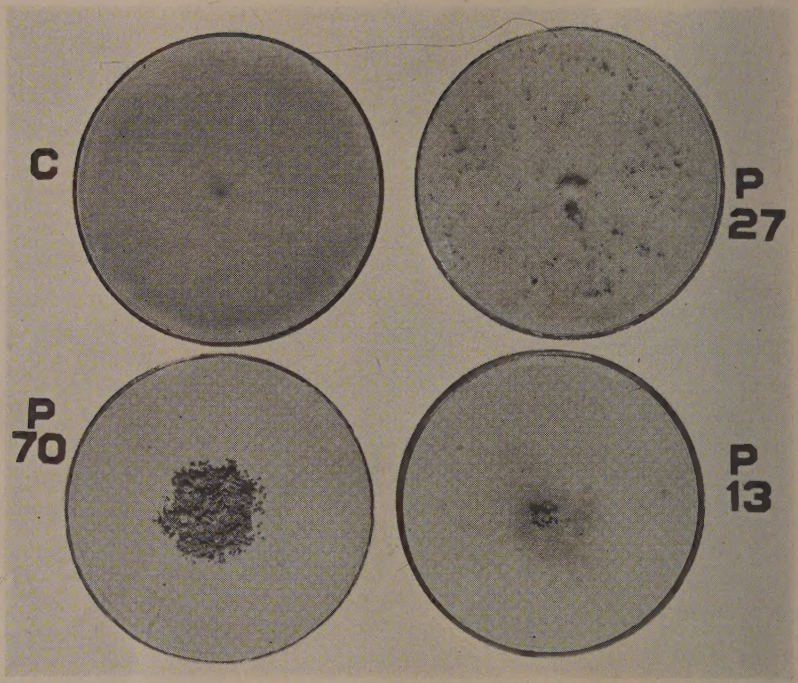
CABBAGE SEEDLINGS AFFECTED WITH WIRE STEM

FIVE-DAYS-OLD CULTURES OF CORTICIUM VAGUM ON POTATO AGAR ADJUSTED TO THE pH VALUES AS INDICATED BY FIGURES ON THE PETRI DISHES



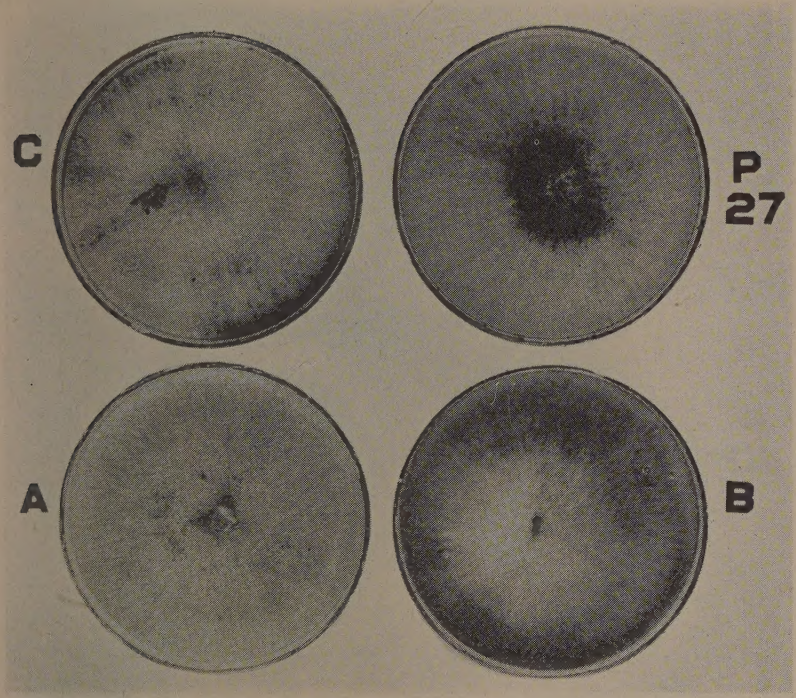
RESPONSE OF FOUR STRAINS OF CORTICIUM VAGUM TO A MEDIUM ADJUSTED TO pH 2.4

C, Cabbage strain, petri dish completely covered with white mycelium. A, Aster strain, petri dish completely covered with white mycelium. P27, Potato strain, showing growth of small diameter, petri dish covered with sclerotia. B, Bamboo strain, petri dish completely covered with a fluffy mass of mycelium, with small sclerotia scattered over surface



RESPONSE OF CABBAGE STRAIN AND OF THREE POTATO STRAINS OF CORTICIUM VAGUM TO A MEDIUM ADJUSTED TO pH 2.7

C, Cabbage strain, petri dish completely covered but no sclerotia produced. P27, potato strain, petri dish completely covered, with a few sclerotia scattered on surface. P70, Potato strain, petri dish not covered, except for an area of 2.6 centimeters in diameter which is completely covered with sclerotia. P13, Potato strain, petri dish completely covered, with a few sclerotia in center



DIFFERENT RATES OF FORMATION OF SCLEROTIA OF FOUR STRAINS OF CORTICIUM VAGUM ON POTATO AGAR ADJUSTED TO PH 7.2

(Age of culture, 12 days)

C, Cabbage strain, with but few sclerotia and with brown mycelium at edges of petri dish. A, Aster strain, with but few minute sclerotia. P27, Potato strain, with a heavy mass of sclerotia in center of petri dish. B, Bamboo strain, petri dish practically covered with dark brown mycelium, with a few minute sclerotia